OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
CALCULATION COVER SHEET

1. QA: QA

2. Calculation Title	
Plutonium/High-Level Vitrified Waste BDBE Dose Calculation	MOL.20001222.0268

3. Document Identifier (including Revision Number)
CAL-WPS-SE-000005 REV 00

4. Total Attachments	5. Attachment Numbers – Number of pages in each
3	I-1; II-23; III - 3

	Print Name	Signature	Date
6. Originator	Jo A. Ziegler	Jo A. Ziegler	11/15/00
7. Checker	Richard P. Morissette	Richard P. Morissette	11/17/00
8. Lead	Thomas D. Dunn	Thomas D. Dunn	11/20/00

9. Remarks

Revision History

10. Revision No.	11. Description of Revision
00	Initial issue.

CONTENTS

Page

TABLES

Page

1. PURPOSE

The purpose of this calculation is to provide a dose consequence analysis of high-level waste (HLW) consisting of plutonium immobilized in vitrified HLW to be handled at the proposed Monitored Geologic Repository at Yucca Mountain for a beyond design basis event (BDBE) under expected conditions using best estimate values for each calculation parameter. In addition to the dose calculation, a plutonium respirable particle size for dose calculation use is derived. The current concept for this waste form is plutonium disks enclosed in cans immobilized in canisters of vitrified HLW (i.e., glass). The plutonium inventory at risk used for this calculation is selected from *Plutonium Immobilization Project Input for Yucca Mountain Total Systems Performance Assessment* (Shaw 1999).

The BDBE examined in this calculation is a nonmechanistic initiating event and the sequence of events that follow to cause a radiological release. This analysis will provide the radiological releases and dose consequences for a postulated BDBE. Results may be considered in other analyses to determine or modify the safety classification and quality assurance level of repository structures, systems, and components. This calculation uses best available technical information because the BDBE frequency is very low (i.e., less than 1.0E-6 events/year) and is not required for License Application for the Monitored Geologic Repository. The results of this calculation will not be used as part of a licensing or design basis.

This calculation is subject to the requirements of DOE/RW/0333P, *Quality Assurance Requirements and Description* (DOE 2000) as determined by procedure QAP-2-0, *Conduct of Activities*. Although QAP-2-0 has been superseded by AP-2.21Q, *Quality Determinations and Planning for Scientific, Engineering, and Regulatory Compliance Activities*, its conclusions remain effective and valid. The work is performed using procedure AP-3.12Q, *Calculations* and is also performed in accordance with development plan, *Design Basis Event Analyses on DOE SNF and Plutonium Can-In-Canister Waste Forms* (CRWMS M&O 1999d). Unverified design inputs are identified and tracked in accordance with AP-3.15Q, *Managing Technical Product Inputs*. Electronic management of information associated with this document as required by procedure AP-SV.1Q, *Control of the Electronic Management of Information*, is ensured by compliance with procedure AP-17.1Q, *Record Source Responsibilities for Inclusionary Records*.

2. METHOD

The calculations described in this document are made with equations solved in Excel 97 spreadsheets used as a calculator. Performing the calculations in spreadsheets offers several advantages: (1) dose estimates are easily understood since calculations are easily checked, (2) the calculations for release, transport, mitigation, and dispersion are easily combined into one electronic document, and (3) dose sensitivity studies can be easily performed.

The equations described in this section are used to calculate source terms, inhalation and air submersion dose calculations; and the following dose calculations applicable to the MGR (Dyer 1999): Committed Dose Equivalent (CDE), Deep Dose Equivalent (DDE), Committed Effective Dose Equivalent (CEDE), Total Effective Dose Equivalent (TEDE), lens of the eye, and skin.

2.1 SOURCE TERMS

The source term released to the environment by a postulated BDBE from the plutonium waste in a plutonium can-in-canister is calculated using equation (1) (DOE 1994, p. 1-2).

$$ST_{j,Pu} = MAR_{j,Pu} \times DR_{j,Pu} \times ARF_{j,Pu} \times RF_{j,Pu} \times LPF_{j,Pu} \tag{1}$$

where,

$ST_{j,Pu}$ - the amount of the j^{th} isotope in the plutonium waste that is released to the environment per canister (Ci/canister)

$MAR_{j,Pu}$ - the material-at-risk of the j^{th} isotope in the plutonium waste per canister (Ci/canister)

$DR_{j,Pu}$ - the fraction of the j^{th} isotope in the material-at-risk that is affected by the BDBE (i.e., the damage ratio) (unitless)

$ARF_{j,Pu}$ - the airborne release fraction of the j^{th} isotope applicable to the BDBE (unitless)

$RF_{j,Pu}$ - the respirable fraction of the j^{th} isotope applicable to the BDBE (unitless)

$LPF_{j,Pu}$ - the leakpath factor of the j^{th} isotope applicable to the BDBE (unitless).

2.2 INHALATION AND SUBMERSION DOSE CALCULATIONS

The inhalation dose to an individual from each isotope in the source term from the plutonium waste per plutonium can-in-canister is calculated using equation (2) while the air submersion dose is calculated using equation (3) per Regulatory Guide 1.109. Note that source term, ST, has been modified by dividing out the respirable fraction, RF, in equation (3) since the air submersion dose should not be modified by the fraction of the source material that is respirable.

$$D^{inh}_{j,k,Pu} = ST_{j,Pu} \times \frac{\chi}{Q} \times BR \times conv \times DCF^{inh}_{j,k} \tag{2}$$

$$D^{sub}_{j,k,Pu} = \frac{ST_{j,Pu}}{RF_{j,Pu}} \times \frac{\chi}{Q} \times conv \times DCF^{sub}_{j,k} \tag{3}$$

where,

$D^{inh}_{j,k,Pu}$ - radiation dose from the j^{th} isotope of the plutonium waste to the k^{th} organ due to inhalation (rem/canister)

$D^{sub}_{j,k,Pu}$ - radiation dose from the j^{th} isotope of the plutonium waste to the k^{th} organ due to air submersion (rem/canister)

k - organ index, where organs are gonads, breast, lungs, red marrow, bone surface, thyroid, remainder, effective, and skin (unitless)

$\frac{\chi}{Q}$ - atmospheric dispersion factor (s/m^3)

BR - breathing rate (m^3/s)

$DCF^{inh}_{j,k}$ - the inhalation dose conversion factor of the j^{th} isotope for the k^{th} organ (Sv/Bq)

$DCF^{sub}_{j,k}$ - the submersion dose conversion factor of the j^{th} isotope for the k^{th} organ ((Sv m^3)/(Bq s))

$conv$ - DCF unit conversion factor: 3.7 x 10^{12} (rem Bq)/(Ci Sv) = 3.7 x 10^{10} (Bq)/(Ci) x 100 (rem/Sv) (Eckerman et al. 1988, p. 121).

The total inhalation dose to an individual from each isotope in the plutonium and HLW source terms in the plutonium can-in-canister is calculated by equation (4).

$$D^{inh}_{j,k} = D^{inh}_{j,k,Pu} + (1-x)D^{inh}_{j,k,HLW} \quad (4)$$

While the air submersion dose is calculated using equation (5).

$$D^{sub}_{j,k} = D^{sub}_{j,k,Pu} + (1-x)D^{sub}_{j,k,HLW} \quad (5)$$

where,

$D^{inh}_{j,k,HLW}$ - radiation dose from the j^{th} isotope of the HLW to the k^{th} organ due to inhalation (rem/canister)

$D^{sub}_{j,k,HLW}$ - radiation dose from the j^{th} isotope of the HLW to the k^{th} organ due to air submersion (rem/canister)

x - the fraction of the plutonium can-in-canister that is plutonium waste (unitless)

$D^{inh}_{j,k}$ - radiation dose from the j^{th} isotope of the waste in a plutonium can-in-canister to the k^{th} organ due to inhalation (rem/canister)

$D^{sub}_{j,k}$ - radiation dose from the j^{th} isotope of the waste in a plutonium can-in-canister to the k^{th} organ due to air submersion (rem/canister).

The HLW doses per HLW canister are based on doses from the *DOE High-Level Vitrified Waste Dose Calculation* (CRWMS M&O 1999b) for a 264-inch (670-centimeter) drop and adjusted for release assumptions used in this calculation. Doses used were obtained from Attachment VIII-7 of CRWMS M&O (1999b) and adjusted by equations (6) and (7):

$$D^{inh}_{j,k,HLW_2} = D^{inh}_{j,k,HLW_1} \times \left(\frac{\chi}{Q_2} \div \frac{\chi}{Q_1} \right) \times LPF \times HLW\% \quad (6)$$

$$D^{sub}_{j,k,HLW_2} = D^{sub}_{j,k,HLW_1} \times \left(\frac{\chi}{Q_2} \div \frac{\chi}{Q_1} \right) \times LPF \times HLW\% \quad (7)$$

where,

D^{inh}_{j,k,HLW_1} - expected radiation dose from the j[th] isotope of the HLW to the k[th] organ due to inhalation (rem) from CRWMS M&O 1999b

D^{inh}_{j,k,HLW_2} - expected radiation dose from the j[th] isotope of the HLW to the k[th] organ due to inhalation (rem)

D^{sub}_{j,k,HLW_1} - expected radiation dose from the j[th] isotope of the HLW to the k[th] organ due to air submersion (rem) from CRWMS M&O 1999b

D^{sub}_{j,k,HLW_2} - expected radiation dose from the j[th] isotope of the HLW to the k[th] organ due to air submersion (rem)

χ / Q_1 - atmospheric dispersion factor (s/m^3) used in CRWMS M&O 1999b

χ / Q_2 - atmospheric dispersion factor (s/m^3) used in this calculation

LPF - leakpath factor for HLW canister (Assumption 3.7)

$HLW\%$ - percentage of HLW in plutonium can-in-canister

2.3 CDE, DDE, CEDE, AND TEDE DOSE CALCULATIONS

The CDE, the DDE, the CEDE, the TEDE, the dose equivalent to the lens of the eye and the dose to the skin and extremities are calculated. The equations used to produce these dose equivalents in terms of the radiation doses calculated in Section 5.3 are shown in the following paragraphs.

The TEDE and the CDE plus DDE dose measures, ignoring the ingestion dose pathway (Assumption 3.1), are expressed as (Dyer 1999):

$$TEDE = CEDE + DDE = \sum_j D^{inh}_{j,effective} + \sum_j D^{sub}_{j,effective} \quad (8)$$

$$CDE_k + DDE = \sum_j D^{inh}_{j,k} + \sum_j D^{sub}_{j,effective} \quad \text{where } k \neq \text{effective or skin} \quad (9)$$

where,

$TEDE$ - total effective dose equivalent (rem)

$CEDE$ - committed effective dose equivalent (rem)

DDE - deep dose equivalent (rem)

CDE_k - committed dose equivalent to the k[th] organ (rem).

The skin and extremities dose is expressed as:

$$SKIN = \sum_j D^{sub}_{j,skin} \quad (10)$$

where,

$SKIN$ - dose to the skin and extremities (rem).

A dose calculation for the lens of the eye is not calculated because Krypton-83m is the only radionuclide with a submersion-to-dose conversion factor listed for the lens of the eye in Eckerman et al. (1998), and the Krypton-83m source term is negligible because of its short half-life. However, NUREG-1567 (NRC 2000) states that compliance with the lens dose equivalent limit is achieved if the sum of the skin dose equivalent and the TEDE does not exceed 15 rem. Therefore, the lens of the eye dose is provided by the summation of the SKIN and TEDE doses.

3. ASSUMPTIONS

3.1 Only inhalation and air submersion doses are considered in calculating offsite doses for BDBEs; the potential doses from ingestion, water immersion, and contaminated soil (groundshine) are negligible. *Basis*: BDBEs and Category 2 design basis events result in acute releases over a period of a few hours and the doses from these pathways may be controlled by interdiction as needed, thus precluding these source term pathways. This assumption has minimal impact on the calculation results and requires no further confirmation. *Usage*: Sections 2.3 and 5.2.3.

3.2 For isotopes with multiple clearance classes, the lung clearance class that yields the highest inhalation dose conversion factor (DCF) is assumed on a per organ basis. *Basis*: This assumption maximizes the calculated inhalation doses. Thus, selecting the largest DCF value on a per organ basis is conservative. The inhalation DCF of an isotope is dependent in part on its chemical form. This dependence is accounted for by the lung clearance class (D [daily], W [weekly], Y [yearly]) used to evaluate the DCF of a given isotope. Some isotopes have only one lung clearance class; others have multiple lung clearance classes. For isotopes with multiple lung clearance classes, the lung clearance class that yields the highest DCF is assumed on a per organ basis. For example, plutonium-238 (which has W- and Y-clearance classes) has the highest lung inhalation DCF for the Y-clearance class, while the other organs have the highest inhalation DCF for the W-clearance class. *Usage*: Section 5.1.5 and Attachment II.

3.3 A respirable fraction (RF) of 1.0 is assumed for this calculation. This fraction will be applied to the release of the radionuclides from plutonium waste in a nonmechanistic BDBE. *Basis*: This assumption is conservative because it is based on all particles released that become airborne being respirable size (i.e., ≤ 10 micron). *Usage:* Sections 5.1.10 and 5.2.1.

3.4 A damage ratio (DR) of 0.25 is selected for use in this calculation (i.e., the bottom layer of plutonium cans are assumed to breach). *Basis*: Using a DR of 0.25 takes credit for the structural integrity provided by the HLW. A finite element calculation performed by CRWMS M&O (1999c, Section 6.3, pages 19-20) evaluated the structural response of the HLW canister during a drop event. The strain and stress intensity values of a 7-m vertical drop were calculated. The maximum calculated strain on the outer surface of the shell (with the plutonium cans) is 0.23 which is less than the elongation of the material (0.40). The maximum calculated strain on the inner surface of the shell is 0.12, which is significantly less than the elongation of the material. These results indicate no breach during a 7-m drop and a DR of 0.25 for the plutonium can-in-canister is conservative for this nonmechanistic BDBE application. *Usage*: Sections 5.1.8 and 5.2.1 and Attachment II.

3.5 Because the plutonium waste form is a compressed powder (Shaw 1999) and the HLW waste form is poured glass (CRWMS M&O 1999b), it is assumed there are no fission product gases or crud available for release. *Basis*: No crud is formed because the surfaces are neither corrosive nor exposed to a corrosive environment such as water, and fission product gases are constituents of a gap release following a fuel rod burst event. *Usage*: Sections 5.1.10 and 5.2.1 and Attachment II.

3.6 The technical information related to the plutonium can-in-canister waste form (e.g., material-at-risk [MAR], isotopic composition, etc.) is assumed to be as shown in Shaw (1999). *Basis:* This information is used directly in this BDBE analysis and has no impact on a quality-related aspect of a structure, system, or component of the Monitored Geologic Repository. *Usage*: Throughout.

3.7 An LPF of 0.01 for a plutonium release from a can-in-canister and an LPF of 0.1 for a HLW release from a canister is assumed for this calculation. The LPF is the fraction of airborne MAR that leaves a confinement barrier after the action of depletion mechanisms such as precipitation, gravitational settling of the released particulate material, or agglomeration, through the confinement barrier. *Basis*: These values are calculated in *Leakpath Factors for Radionuclide Releases from Breached Confinement Barriers* (CRWMS M&O 2000, page 32) and are reasonable for BDBE use. *Usage*: Sections 2.2, 5.1.6, 5.1.11, 5.2.1, and 6.0 and Attachment II.

3.8 The airborne release fraction (ARF) for the plutonium waste form inside a can-in-canister selected for use in this analysis is 3.0×10^{-4}. *Basis*: This value is derived in Attachment III and is corroborated by Shaw (1999, Section 7, page 27). This value is conservative and considered reasonable for BDBE use because it represents the best estimate under the expected conditions of the material (i.e., the anticipated loads resulting from a canister drop). *Usage*: Sections 5.2.1, 5.1.10, and 6.0 and Attachment II.

3.9 A distance of 11 km is assumed as the nearest point of public access from the waste handling building for purposes of a dose receptor point. *Basis*: This is a conservative assumption that will not require confirmation because the distance between the waste handling building and the nearest point of public access on the proposed Land Withdrawal Boundary (to the West) is 11.65 kilometers (DTN: MO0001YMP00001.000). Other points on the proposed Land Withdrawal Boundary which are closer to the waste handling building are on either Nevada Test Site or Nellis Air Force Base property where public access is prohibited. *Usage*: This assumption is used throughout the calculation.

4. USE OF COMPUTER SOFTWARE AND MODELS

4.1 DOCUMENTATION OF SOFTWARE

No software routines, macros, or models, as defined by AP-SI.1Q, are used in this analysis. Microsoft Excel spreadsheets using existing functions in Excel were used to multiply and divide applicable terms for dose equations and respirable fractions and is considered appropriate for this application. The spreadsheets used in this calculation have no specific version; they are explicitly coupled with this calculation and its documentation. No changes can be made to the spreadsheets without a revision of this calculation document or the production of a separate calculation that documents the changes.

The checking process provides verification that the results documented in Attachments II and III are correct for the input data contained therein.

The spreadsheets used in this calculation were developed in Excel 97 SR-2 under the Windows 95 operating system on an IBM-compatible PC. The spreadsheets used herein have been developed to function under Excel 97 on a PC platform with the Windows 95 operating system. Execution of the spreadsheets under a different version of Excel, on a different computing platform, and/or with a different operating system may impact the veracity of their results.

4.2 SPREADSHEET INFORMATION

This calculation uses Excel spreadsheets to generate BDBE source terms and dose consequences (Attachment II). The Excel spreadsheets contained in Attachment II are described below:

- Table II-1 - Lists the MAR in the plutonium cans placed in a canister (no calculations).
- Tables II-2 and II-3 - DCFs for isotopes contained in the plutonium cans (see Section 5.2.5) (no calculations).
- Tables II-4 and II-5 - Calculation of plutonium dose potential for a plutonium can-in-canister for the 17-metric-ton case. The calculations performed in this sheet involve multiplying the MAR by the DCFs and the conversion factors for sieverts to rem and curies to bequerels for each radioisotope and each organ. These source terms are then added together for each organ. Note: The calculations on this table were verified by manual calculations.
- Tables II-6 and II-7 – Calculation of plutonium dose potential for a plutonium can-in-canister for the 50-metric-ton case. The calculations performed in this sheet involve multiplying the MAR by the DCFs and the conversion factors for sieverts to rem and curies to bequerels for each radioisotope and each organ. These source terms are then added together for each organ. Note: The calculations on this table were verified by manual calculations.
- Tables II-8 and II-9 - HLW Inputs – Organ doses as calculated in *DOE High Level Vitrified Waste Dose Calculation* (CRWMS M&O, 1999b) are listed and adjusted for assumptions used in this calculation. Adjustments include a multiplication factor to use the χ/Q applicable to this calculation, multiplication of the LPF for the canister, and multiplication of the percentage of glass contained in the canister (after displacement by plutonium) (see Section 5.1.6). Note: The calculations on this table were verified by manual calculations.
- Tables II-10 and II-11 – Unfiltered Plutonium Canister Dose (using 50% acute χ/Q) - calculation of unmitigated doses for a plutonium/HLW canister with 12% of the HLW displaced by plutonium waste (17-metric-ton case). The potential plutonium dose is

multiplied by the RF, ARF, LPF, breathing rate, χ/Q, and the mitigation factor for determination of the offsite dose. Tables II-18 and II-19 repeat this calculation using a conservative LPF. Note: The calculations on these tables were verified by manual calculations.

- Tables II-12 and II-13 – Filtered Plutonium Canister Dose (using 50% acute χ/Q) - calculation of mitigated doses for a plutonium/HLW canister with 12% of the HLW displaced by plutonium waste (17-metric-ton case). The potential plutonium dose is multiplied by the RF, ARF, LPF, breathing rate, χ/Q, and the mitigation factor for determination of the offsite dose. Tables II-20 and II-21 repeat this calculation using a conservative LPF. Note: The calculations on these tables were verified by manual calculations.

- Tables II-14 and II-15 – Unfiltered Plutonium Canister Dose (using maximum acute χ/Q) - calculation of unmitigated doses for a plutonium/HLW canister with 12% of the HLW displaced by plutonium waste (17-metric-ton case). The potential plutonium dose is multiplied by the RF, ARF, LPF, breathing rate, χ/Q, and the mitigation factor for determination of the offsite dose. Tables II-22 and II-23 repeat this calculation using a conservative LPF. Note: The calculations on these tables were verified by manual calculations.

- Tables II-16 and II-17 – Filtered Plutonium Canister Dose (using maximum acute χ/Q) - calculation of mitigated doses for a plutonium/HLW canister with 12% of the HLW displaced by plutonium waste (17-metric-ton case). The potential plutonium dose is multiplied by the RF, ARF, LPF, breathing rate, χ/Q, and the mitigation factor for determination of the offsite dose. Tables II-24 and II-25 repeat this calculation using a conservative LPF. Note: The calculations on these tables were verified by manual calculations.

Existing functions in Microsoft Excel were used to generate the chart shown in Attachment III. The Excel chart plots test data by showing lines that were calculated by regression analysis. The Excel program was used as a calculator and plotter using existing functions. Note: The calculations on this table were verified by manual calculations.

5. CALCULATION

5.1 DESCRIPTION FOR DOSE CALCULATION

The purpose of this radiological analysis is to estimate the radioactive releases and resultant doses per canister to the public from a BDBE that is assumed to occur within the waste handling building. In this calculation, doses received are by an offsite individual at the nearest site boundary from the radionuclide release point (i.e., 11 km for this calculation). Doses to individual organs and to the whole body are calculated, respectively, for exposure via inhalation and submersion.

The calculations, as described in Section 2, are performed for the HLW and the plutonium can-in-canister waste form and are shown in Attachment II. See *DOE High Level Vitrified Waste Dose Calculation* (CRWMS M&O 1999b) for details on the doses produced by the HLW waste form.

5.1.1 Source Terms - Radionuclide Inventories

The radionuclides selected for this calculation and the activities of those radionuclides are shown in Table 1 (Shaw 1999, Table 4.6, page 19) (Assumption 3.6). Table 1 lists the activity for the case where only 17-metric-tons of plutonium, which contains impurities making it unsuitable for mixed oxide reactor fuel, is disposed and the case where 50-metric tons of surplus plutonium are disposed. Selection of the 17-metric-ton case for calculating a BDBE 11-km boundary dose was made based on the results of calculating dose potential per canister in Attachment II, Tables II-4 through II-7. The results of these calculations show that the 17-metric-ton case results in the higher dose. The remaining calculations were performed on the 17-metric-ton case only.

Table 1. Average Total Activity of Immobilized Waste Form

Isotope	Activity (Ci per Canister)	
	17-Metric-Ton Case	50-Metric-Ton Case
Plutonium-238	115	56
Plutonium-239	1517	1555
Plutonium-240	517	404
Plutonium-241	4452	2680
Plutonium-242	9.2E-2	4.3E-2
Americium-241	675	406
Uranium-234	< 1E-5	< 5E-6
Uranium-235	2.2E-3	1.0E-3
Uranium-238	1.8E-2	1.8E-2
Thorium-232	< 3E-5	< 3E-5

5.1.2 Plutonium Mass

The mass of the plutonium within the plutonium can-in-canister is from Section 2 of Shaw (1999). Table 2 presents the data for the plutonium waste form.

Table 2. Plutonium Waste Form Mass Data

Property	Value
Disks per can	20
Cans per tube	4
Tubes per plutonium can-in-canister	7
Ceramic mass per can	9.2 kg
Maximum plutonium per can-in-canister	27 kg
Maximum fraction of HLW displaced by plutonium in a canister	0.12

5.1.3 Atmospheric Dispersion Factors

The atmospheric dispersion factors (χ/Qs) used in this calculation were extracted from *Calculations of Acute and Chronic "Chi/Q" Dispersion Estimates for a Surface Release* (CRWMS M&O 1999a, Table 3, page 11) for the location of the dose receptor (see Section 5.1.9). Dose calculations were produced using the best estimate value under expected conditions (i.e., an interpolated 50% acute χ/Q value of 4.92×10^{-6} sec/m^3) and using the worst-case air dispersion conditions (i.e., an interpolated maximum acute χ/Q of 2.17×10^{-5} sec/m^3). The referenced report values were calculated using the methodology outlined in Regulatory Guide 1.145. The 50% acute χ/Q values for the maximum sector were used for dispersion calculations and are applicable to nonmechanistic BDBE events under expected conditions for dispersion. The χ/Q maximum acute values for the maximum sector were used for dispersion calculations and are applicable to nonmechanistic BDBE events using a worst-case condition for dispersion.

5.1.4 Breathing Rate

An adult breathing rate of 3.33×10^{-4} m^3/s (20-liters/min) was used for dose calculations. This value is based on the Reference Man breathing rate established by the International Commission on Radiological Protection (ICRP 1975, p. 346) and accepted by the Nuclear Regulatory Commission for accident analysis (NRC 1997, p. 7-7). This breathing rate is based on the volume intake of air for "light activity" and is considered to be appropriate for BDBE accident scenarios resulting in short-term ($\leq$ 8-hour) exposures to the public at the nearest site boundary.

5.1.5 Inhalation and Submersion Dose Conversion Factors

Inhalation and air submersion DCFs are taken from Federal Guidance Report 11 and Federal Guidance Report 12, respectively (Eckerman et al. 1988 and Eckerman et al. 1993). The DCFs used in this analysis are based on the lung clearance that yields the highest inhalation dose (Assumption 3.2). The DCFs used in this calculation are listed in Attachment II.

5.1.6 Doses from the HLW Waste Form

The HLW doses per canister for the 264-inch drop of a HLW waste form are obtained from the *DOE High-Level Vitrified Waste Dose Calculation* for SRS HLW (CRWMS M&O 1999b, Attachment VIII-7). Tables II-8 and II-9 of Attachment II present the adjusted HLW doses for use in this calculation. Adjustments were made to the referenced doses to apply the χ/Q applicable to this calculation, to apply the LPF for the canister (Assumption 3.7), and reduction of the dose by the percentage of glass contained in the canister (after displacement by plutonium).

5.1.7 Filter Mitigation Factor

A single-stage high-efficiency particulate air (HEPA) filter has, by definition, an efficiency of no less than 99.97% (ASME AG-1-1997). Hence, for this BDBE analysis, a mitigation factor of 3.0×10^{-4} can be applied to particulate radionuclide releases that are drawn through the exhaust HEPA filters by the waste handling building heating, ventilation, and air-conditioning system.

5.1.8 Damage Ratio

The DR is the percentage of damaged plutonium cans during a BDBE (Assumption 3.4). The plutonium dose potential is multiplied by the DR during calculation of the offsite dose.

5.1.9 Location of Dose Receptor

The selected location of the dose receptor for this calculation is 11 kilometers (km) from the waste handling building. The distance between the waste handling building and the nearest point of public access on the proposed Land Withdrawal Boundary (to the West) is 11.65 kilometers (DTN: MO0001YMP00001.000). Other points on the proposed Land Withdrawal Boundary which are closer to the waste handling building are on either Nevada Test Site or Nellis Air Force Base property where public access is prohibited.

5.1.10 Airborne Release and Respirable Fraction for Plutonium

The airborne release fraction (ARF) for the plutonium waste form inside a can-in-canister selected for use in this analysis is 3.0×10^{-4} (Assumption 3.8). Each of the radionuclides listed in Table 1 is released in particulate form rather than as a gas or a volatile. There are no gases in the plutonium waste form (Assumption 3.5) and the RF used for this calculation is 1 (Assumption 3.3). Thus, a single ARF may be used to represent the release of particulate due to a potential BDBE. The ARF is applied to the release of the radionuclides from plutonium waste in a BDBE that may potentially cause a canister to breach. No credit is taken for holdup of particulate in the HLW glass material.

5.1.11 Leakpath Factors

A leakpath factor (LPF) of 0.1 for the plutonium can and 0.1 for the HLW canister is used in this calculation (Assumption 3.7). The calculation for plutonium releases, therefore, uses a total LPF of 0.01 because of the two barriers to release (i.e., the plutonium can and the HLW canister, [$0.1 \times 0.1 = 0.01$]). The adjusted HLW release uses 0.1 for the single barrier (i.e., 0.1 for the HLW canister).

5.1.12 High-Level Waste Release Fractions

The ARF/RF for the HLW waste form is based on a maximum drop height of 264 inches (671 centimeters). This data is based on the *DOE High Level Vitrified Waste Dose Calculation* (CRWMS M&O 1999b, Attachment VI).

5.2 CONSEQUENCE ANALYSIS

This radiological analysis estimates the radioactive releases and resultant doses to the public from a nonmechanistic BDBE that is assumed to occur within the waste handling building. The doses received by an offsite individual at the nearest site boundary from the radionuclide release point are calculated. Doses to individual organs and to the whole body are calculated for exposure through inhalation and submersion.

The dose produced by both the plutonium waste and the HLW contained in a plutonium can-in-canister must be considered for the BDBE. According to Shaw (1999, Section 2), the plutonium bearing canisters contain approximately 88% of their maximum capacity for HLW glass (i.e., plutonium makes up approximately 12% of these canisters). Thus, considering HLW is homogeneously distributed through a HLW canister, the dose associated with the HLW in a canister containing plutonium is the dose from a canister containing only HLW reduced by 12%. The dose associated with HLW is adjusted for the dose associated with each organ prior to any additions to doses associated with the plutonium (see Tables II-8 and II-9 of Attachment II).

5.2.1 Source Terms

The source terms are formed by the radionuclides available for release if the engineered barriers (i.e., the canisters) are breached. A person engulfed by the released radioactive plume, who inhales the radionuclides suspended in the plume, receives the inhalation dose. The inhalation doses are the 50-year committed dose equivalents. No crud or fission product gases are associated with these canisters (Assumption 3.5).

Source terms are generated in units of curies so that they may be easily converted to units of dose. Each of the isotopes in the source terms is evaluated for its dose contribution to the gonad, breast, lung, red marrow, bone surface, thyroid, remainder, and whole body. Attachment II details these source term calculations for the plutonium in the plutonium can-in-canister. Details of the source term calculation for HLW (as modified in this calculation) can be found in the *DOE High Level Vitrified Waste Dose Calculation* (CRWMS M&O 1999b). The HLW dose results from this calculation will be combined with the dose calculations for the plutonium waste established in this analysis (as shown in Section 5.3.2) to determine the total potential dose produced by a breached canister containing plutonium in cans and HLW.

The source term released to the environment by a postulated BDBE for the plutonium waste in a can-in-canister is calculated by Equation (1) (see Section 2.1). For plutonium waste in a can-in-canister, the damage ratio (DR) is equal to 0.25 (Assumption 3.4). The RF is assumed equal to one (Assumption 3.3) for each isotope. The ARF is assumed equal to 3.0×10^{-4} for each isotope in this analysis (Assumption 3.8). The LPF is assumed equal to 0.01 for plutonium and 0.1 for HLW for each isotope in this analysis (Assumption 3.7).

5.2.2 Inhalation and Submersion Dose Calculations

Equations used to calculate inhalation and submersion doses are shown in Section 2.2. The inhalation dose to an individual from each isotope in the source term from the plutonium waste per plutonium can-in-canister is calculated by Equation (2) and the air submersion dose is calculated by Equation (3). The total inhalation dose to an individual from each isotope in the source term in the plutonium can-in-canister is calculated by Equation (4) and the air submersion dose is calculated by Equation (5).

The radiation doses from the HLW are calculated in the *DOE High Level Vitrified Waste Dose Calculation* (CRWMS M&O 1999b). The maximum fraction of the plutonium can-in-canister that is plutonium waste is found in Table 2. Note that the radiation dose from the plutonium waste in the above equations is on a per canister basis, which assumes some maximum fraction of a canister contains plutonium waste. The values calculated for HLW are based on a canister filled entirely with HLW. Note that the parameters in equations (1) through (5) have been used in Attachment II spreadsheets as described in Section 4.2.

5.2.3 CDE, DDE, CEDE, and TEDE Calculations

The TEDE and the CDE + DDE dose measures, ignoring the ingestion dose pathway (Assumption 3.1), are expressed as Equations (8) and (9); the skin and extremities dose is calculated using Equation (10) (see Section 2.3). These calculations are shown in Attachment II.

5.3 BDBE DOSE CONSEQUENCES

Equations (1) through (10) are used to establish the dose consequences per canister. In the unmitigated calculation, no credit is taken for any hindrance due to any component containing the canisters or the waste handling building and other structures may provide against the leakage of the released radionuclides to the site boundary. See Attachment II for dose consequence calculations.

6. RESULTS

This analysis may be affected by technical product input information that requires confirmation. Any changes to the document that may occur as a result of completing the confirmation activities will be reflected in subsequent revisions. The status of the input information quality may be confirmed by review of the Document Input Reference System database.

The offsite dose consequence results from the calculations in Attachment II for the 17-metric-ton case are summarized in Table 3 using the best-estimate parameters. Table 3 summarizes the unmitigated doses and the mitigated dose consequences, which were produced assuming the presence of HEPA filters. Table 4 presents offsite dose consequences from the calculations in Attachment II, but using the most conservative leakpath factor (i.e., 1). Table 4 also shows the sensitivity to the expected (i.e., 50% acute) χ/Q to the worst-case (i.e., maximum acute) χ/Q.

Inputs that may significantly impact the dose results (e.g., increase doses) in this calculation include: (1) the airborne release fraction (Assumption 3.8), (2) the activity of the radionuclides in the plutonium waste (Assumption 3.6), (3) the percentage of plutonium in the canisters, and (4)

LPF values (Assumption 3.7). The derivation of the plutonium ARF based on ANSI/ANS-5.10 must be caveated by the observation that all data were taken on laboratory scale samples (i.e., cm-sized pellets or glass cylinders). The validity of extrapolating the results to canister-scale impacts is uncertain.

Table 3. Dose Consequences for Breached Plutonium Can-In-Canister (using best-estimate parameters)

Fraction of HLW Displaced by Plutonium	Dose per Plutonium Can-in-Canister (rem)			
	TEDE	Highest CDE + DDE	Skin	Lens of the Eye
0.12 (Unmitigated, 50% Acute χ/Q)	5.04E-3	8.59E-2 (bone surface)	2.80E-7	5.04E-3
0.12 (Mitigated, 50% Acute χ/Q)	1.51E-6	2.58E-5 (bone surface)	8.41E-11	1.51E-6
0.12 (Unmitigated, 99.5% Acute χ/Q)	2.22E-2	3.79E-1 (bone surface)	1.24E-6	2.22E-2
0.12 (Mitigated, 99.5% Acute χ/Q)	6.67E-6	1.14E-4 (bone surface)	3.71E-10	6.67E-6

Table 4. Dose Consequences for Breached Plutonium Can-In-Canister (using most conservative leakpath factor)

Fraction of HLW Displaced by Plutonium	Dose per Plutonium Can-in-Canister (rem)			
	TEDE	Highest CDE + DDE	Skin	Lens of the Eye
0.12 (Unmitigated, 50% Acute χ/Q)	1.89E-1	3.38E+0 (bone surface)	2.80E-6	1.89E-1
0.12 (Mitigated, 50% Acute χ/Q)	5.67E-5	1.01E-3 (bone surface)	8.41E-10	5.67E-5
0.12 (Unmitigated, 99.5% Acute χ/Q)	8.34E-1	1.49E+1 (bone surface)	1.24E-5	8.34E-1
0.12 (Mitigated, 99.5% Acute χ/Q)	2.50E-4	4.47E-3 (bone surface)	3.71E-9	2.50E-4

7. REFERENCES

7.1 DOCUMENTS CITED

Avallone, E.A. and Baumeister, T., III, eds. 1987. *Marks' Standard Handbook for Mechanical Engineers.* 9th Edition. New York, New York: McGraw-Hill. TIC: 206891.

Civilian Radioactive Waste Management System Management and Operating Contractor (CRWMS M&O) 1999a. *Calculations of Acute and Chronic "Chi/Q" Dispersion Estimates for a Surface Release.* TDR-MGR-MM-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000106.0439.

CRWMS M&O 1999b. *DOE High-Level Vitrified Waste Dose Calculation.* CAL-WPS-SE-000002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990720.0403.

CRWMS M&O 1999c. *HLW Canister and Can-in-Canister Drop Calculation.* BBAA00000-01717-0210-00023 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990922.0321.

CRWMS M&O 1999d. *Design Basis Event Analyses on DOE SNF and Plutonium Can-In-Canister Waste Forms.* Development Plan TDP-WHS-SE-000002. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000107.0065.

CRWMS M&O 2000. *Leakpath Factors for Radionuclide Releases from Breached Confinement Barriers.* Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000901.0021.

DOE (U.S. Department of Energy) 1994. *Analysis of Experimental Data.* Volume 1 of *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities.* DOE-HDBK-3010-94. Washington, D.C.: U.S. Department of Energy. TIC: 233366.

DOE 2000. *Quality Assurance Requirements and Description.* DOE/RW-0333P, Rev. 10. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20000427.0422.

Dyer, J.R. 1999. "Revised Interim Guidance Pending Issuance of New U.S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01, July 22, 1999), for Yucca Mountain, Nevada." Letter from J.R. Dyer (DOE/YMSCO) to D.R. Wilkins (CRWMS M&O), September 3, 1999, OL&RC:SB-1714, with enclosure, "Interim Guidance Pending Issuance of New NRC Regulations for Yucca Mountain (Revision 01)." ACC: MOL.19990910.0079.

Eckerman, K.F. and Ryman, J.C. 1993. *External Exposure to Radionuclides in Air, Water, and Soil, Exposure-to-Dose Coefficients for General Application, Based on the 1987 Federal Radiation Protection Guidance.* EPA-402-R-93-081. Federal Guidance Report No. 12. Washington, D.C.: U.S. Environmental Protection Agency, Office of Radiation and Indoor Air. TIC: 225472.

Eckerman, K.F.; Wolbarst, A.B.; and Richardson, A.C.B. 1988. *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion.* EPA 520/1-88-020. Federal Guidance Report No. 11. Washington, D.C.: U.S. Environmental Protection Agency. TIC: 203350.

ICRP (International Commission on Radiological Protection) 1975. *Report of the Task Group on Reference Man: A Report Prepared by a Task Group of Committee 2 of the International Commission on Radiological Protection.* ICRP Number 23. Tarrytown, New York: Elsevier Science. TIC: 237218.

Jardine, L.J.; Mecham, W.J.; Reedy, G.T.; and Steindler, M.J. 1982. *Final Report of Experimental Laboratory-Scale Brittle Fracture Studies of Glasses and Ceramics.* ANL-82-39. Argonne, Illinois: Argonne National Laboratory. TIC: 225736.

NRC (U.S. Nuclear Regulatory Commission) 1997. *Standard Review Plan for Dry Cask Storage Systems.* NUREG-1536. Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 232373.

NRC 2000. *Standard Review Plan for Spent Fuel Dry Storage Facilities.* NUREG-1567. Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 247929.

Shaw, H., ed. 1999. *Plutonium Immobilization Project Input for Yucca Mountain Total Systems Performance Assessment.* PIP-99-107. Livermore, California: Lawrence Livermore National Laboratory. TIC: 245437.

7.2 SOURCE DATA

MO0001YMP00001.000. Minimum Distances from Selected Yucca Mountain Project Sites to Public Lands. Submittal date: 01/26/2000.

7.3 CODES, STANDARDS, AND REGULATIONS

ANSI/ANS-5.10-1998. *Airborne Release Fractions at Non-Reactor Nuclear Facilities.* La Grange Park, Illinois: American Nuclear Society. TIC: 235073.

ASME AG-1-1997. *Code on Nuclear Air and Gas Treatment.* New York, New York: American Society of Mechanical Engineers. TIC: 247207.

Regulatory Guide 1.109, Rev. 1. 1977. *Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I.* Washington, D.C.: U.S. Nuclear Regulatory Commission. Readily available.

Regulatory Guide 1.145, Rev. 1. 1982. *Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants.* Washington, D.C.: U.S. Nuclear Regulatory Commission. Readily available.

7.4 PROCEDURES

AP-2.21Q, Rev. 0. *Quality Determinations and Planning for Scientific, Engineering, and Regulatory Compliance Activities.* Acc: MOL.20000802.0003.

AP-3.12Q, Rev. 0, ICN 3. *Calculations.* ACC: MOL.20001026.0084.

AP-3.15Q, Rev. 2, ICN 0. *Managing Technical Product Inputs.* ACC: MOL.20001109.0051.

AP-SI.1Q, Rev. 2, ICN 4, ECN 1. *Software Management.* ACC: MOL.20001019.0023.

AP-SV.1Q, Rev. 0, ICN 2. *Control of the Electronic Management of Information.* ACC: MOL.20000831.0065.

AP-17.1Q, Rev. 1, ICN2. *Record Source Responsibilities for Inclusionary Records.* ACC: MOL.19991217.0505.

QAP-2-0, Rev. 5. *Control of Activities.* ACC: MOL.19980826.0209.

8. ATTACHMENTS

Attachment I	Acronyms
Attachment II	Dose Consequence Analysis for Plutonium Can-in-Canisters
Attachment III	Plutonium Respirable Fractions

Attachment I

Acronyms

ARF	Airborne Release Fraction
BR	Breathing Rate
CDE	Committed Dose Equivalent
CEDE	Committed Effective Dose Equivalent
CP	Cold Press
BDBE	Beyond Design Basis Event
DCF	Dose Conversion Factor
DDE	Deep Dose Equivalent
DR	Damage Ratio
HEPA	High-Efficiency Particulate Air
HLW	High-Level Waste
HP	Hot Press
LPF	Leakpath Factor
MAR	Material-at-Risk
RF	Respirable Fraction
ST	Source Term
TEDE	Total Effective Dose Equivalent

Attachment II

Dose Consequence Analysis for Plutonium Can-in-Canisters

This attachment contains the Excel 97 spreadsheets used to calculate the dose for the plutonium can-in-canister, which includes the HLW in the canister.

Table II-1. Material at Risk

Isotope	Activity in 2010 (Ci per Canister)	
	50-Metric-Ton Case	17-Metric-Ton Case
Pu-238	5.60E+01	1.15E+02
Pu-239	1.56E+03	1.52E+03
Pu-240	4.04E+02	5.17E+02
Pu-241	2.68E+03	4.45E+03
Am-241	4.06E+02	6.75E+02
Pu-242	4.30E-02	9.20E-02
U-234	5.00E-06	1.00E-05
U-235	1.00E-03	2.20E-03
U-238	1.80E-02	1.80E-02
Th-232	3.00E-05	3.00E-05

Reference: Shaw 1999, page 19.

Table II-2. Exposure-to-Dose Conversion Factors for Inhalation								
Isotope	Committed Dose Equivalent per Unit Intake (Sv/Bq)							
	Gonad	Breast	Lung	R Marrow	B Surface	Thyroid	Remainder	Effective
Pu-238	2.80E-05	1.00E-09	3.20E-04	1.52E-04	1.90E-03	9.62E-10	7.02E-05	1.06E-04
Pu-239	3.18E-05	9.22E-10	3.23E-04	1.69E-04	2.11E-03	9.03E-10	7.56E-05	1.16E-04
Pu-240	3.18E-05	9.51E-10	3.23E-04	1.69E-04	2.11E-03	9.05E-10	7.56E-05	1.16E-04
Pu241	6.82E-07	3.06E-11	3.18E-06	3.36E-06	4.20E-05	1.24E-11	1.31E-06	2.23E-06
Am-241	3.25E-05	2.67E-09	1.84E-05	1.74E-04	2.17E-03	1.06E-09	7.82E-05	1.20E-04
Pu-242	3.02E-05	9.45E-10	3.07E-04	1.61E-04	2.01E-03	8.79E-10	7.18E-05	1.11E-04
U-234	2.50E-08	2.50E-08	2.98E-04	6.98E-07	1.09E-05	2.50E-08	9.26E-07	3.58E-05
U-235	2.37E-08	2.38E-08	2.76E-04	6.58E-07	1.01E-05	2.37E-08	8.59E-07	3.32E-05
U-238	2.23E-08	2.23E-08	2.66E-04	6.58E-07	9.78E-06	2.22E-08	8.22E-07	3.20E-05
Th-232	7.62E-07	7.72E-07	9.40E-04	8.93E-04	1.11E-02	7.44E-07	1.87E-06	4.43E-04

Reference: Eckerman et al. 1988

Table II-3. Exposure-to-Dose Conversion Factors for Submersion										
Isotope	Committed Dose Equivalent per Unit Intake (Sv/s per Bq/m^3)									
	Gonad	Breast	Lung	R Marrow	B Surface	Thyroid	Remainder	Effective	Skin	Lens of Eye
Pu-238	6.56E-18	1.27E-17	1.06E-18	1.68E-18	9.30E-18	4.01E-18	1.99E-18	4.88E-18	4.09E-17	0.00E+00
Pu-239	4.84E-18	7.55E-18	2.65E-18	2.67E-18	9.47E-18	3.88E-18	2.86E-18	4.24E-18	1.86E-17	0.00E+00
Pu-240	6.36E-18	1.23E-17	1.09E-18	1.65E-18	9.26E-18	3.92E-18	1.96E-18	4.75E-18	3.92E-17	0.00E+00
Pu241	7.19E-20	8.67E-20	6.48E-20	5.63E-20	2.19E-19	6.98E-20	6.09E-20	7.25E-20	1.17E-19	0.00E+00
Am-241	8.58E-16	1.07E-15	6.74E-16	5.21E-16	2.87E-15	7.83E-16	6.34E-16	8.18E-16	1.28E-15	0.00E+00
Pu-242	5.34E-18	1.03E-17	9.69E-19	1.43E-18	7.90E-18	3.32E-18	1.68E-18	4.01E-18	3.27E-17	0.00E+00
U-234	8.79E-18	1.44E-17	4.38E-18	4.20E-18	1.99E-17	6.69E-18	4.80E-18	7.63E-18	4.25E-17	0.00E+00
U-235	7.05E-15	8.11E-15	6.75E-15	6.15E-15	1.84E-14	7.05E-15	6.37E-15	7.20E-15	8.64E-15	0.00E+00
U-238	4.39E-18	8.54E-18	9.96E-19	1.24E-18	7.40E-18	2.72E-18	1.51E-18	3.41E-18	2.91E-17	0.00E+00
Th-232	9.34E-18	1.36E-17	6.37E-18	5.52E-18	2.60E-17	7.90E-18	6.34E-18	8.72E-18	3.44E-17	0.00E+00

Reference: Eckerman et al. 1993

Table II-4. Plutonium Inhalation Dose Potential for 17-Metric-Ton Case

Isotope	Rem/Canister							
	Gonad	Breast	Lung	R Marrow	B Surface	Thyroid	Remainder	Effective
Pu-238	1.19E+10	4.26E+05	1.36E+11	6.47E+10	8.08E+11	4.09E+05	2.99E+10	4.51E+10
Pu-239	1.78E+11	5.18E+06	1.81E+12	9.49E+11	1.18E+13	5.07E+06	4.24E+11	6.51E+11
Pu-240	6.08E+10	1.82E+06	6.18E+11	3.23E+11	4.04E+12	1.73E+06	1.45E+11	2.22E+11
Pu-241	1.12E+10	5.04E+05	5.24E+10	5.53E+10	6.92E+11	2.04E+05	2.16E+10	3.67E+10
Am-241	8.12E+10	6.67E+06	4.60E+10	4.35E+11	5.42E+12	2.65E+06	1.95E+11	3.00E+11
Pu-242	1.03E+07	3.22E+02	1.05E+08	5.48E+07	6.84E+08	2.99E+02	2.44E+07	3.78E+07
U-234	9.25E-01	9.25E-01	1.10E+04	2.58E+01	4.03E+02	9.25E-01	3.43E+01	1.32E+03
U-235	1.93E+02	1.94E+02	2.25E+06	5.36E+03	8.22E+04	1.93E+02	6.99E+03	2.70E+05
U-238	1.49E+03	1.49E+03	1.77E+07	4.38E+04	6.51E+05	1.48E+03	5.47E+04	2.13E+06
Th-232	8.46E+01	8.57E+01	1.04E+05	9.91E+04	1.23E+06	8.26E+01	2.08E+02	4.92E+04
Total	**3.44E+11**	**1.46E+07**	**2.67E+12**	**1.83E+12**	**2.28E+13**	**1.01E+07**	**8.16E+11**	**1.25E+12**

Table II-5. Plutonium Submersion Dose Potential for 17-Metric-Ton Case

Isotope	(Rem-m³)/(s-Canister)									
	Gonad	Breast	Lung	R Marrow	B Surface	Thyroid	Remainder	Effective	Skin	Lens Eye
Pu-238	2.79E-03	5.40E-03	4.51E-04	7.15E-04	3.96E-03	1.71E-03	8.47E-04	2.08E-03	1.74E-02	0.00E+00
Pu-239	2.72E-02	4.24E-02	1.49E-02	1.50E-02	5.32E-02	2.18E-02	1.61E-02	2.38E-02	1.04E-01	0.00E+00
Pu-240	1.22E-02	2.35E-02	2.09E-03	3.16E-03	1.77E-02	7.50E-03	3.75E-03	9.09E-03	7.50E-02	0.00E+00
Pu-241	1.18E-03	1.43E-03	1.07E-03	9.27E-04	3.61E-03	1.15E-03	1.00E-03	1.19E-03	1.93E-03	0.00E+00
Am-241	2.14E+00	2.67E+00	1.68E+00	1.30E+00	7.17E+00	1.96E+00	1.58E+00	2.04E+00	3.20E+00	0.00E+00
Pu-242	1.82E-06	3.51E-06	3.30E-07	4.87E-07	2.69E-06	1.13E-06	5.72E-07	1.37E-06	1.11E-05	0.00E+00
U-234	3.25E-10	5.33E-10	1.62E-10	1.55E-10	7.36E-10	2.48E-10	1.78E-10	2.82E-10	1.57E-09	0.00E+00
U-235	5.74E-05	6.60E-05	5.49E-05	5.01E-05	1.50E-04	5.74E-05	5.19E-05	5.86E-05	7.03E-05	0.00E+00
U-238	2.92E-07	5.69E-07	6.63E-08	8.26E-08	4.93E-07	1.81E-07	1.01E-07	2.27E-07	1.94E-06	0.00E+00
Th-232	1.04E-09	1.51E-09	7.07E-10	6.13E-10	2.89E-09	8.77E-10	7.04E-10	9.68E-10	3.82E-09	0.00E+00
Total	**2.19E+00**	**2.75E+00**	**1.70E+00**	**1.32E+00**	**7.25E+00**	**1.99E+00**	**1.61E+00**	**2.08E+00**	**3.40E+00**	**0.00E+00**

NOTES

[A] Inhalation Source Term = [MAR (Ci/canister)] [DCF(Sv/Bq)] [3.7×10^{10} Bq/Ci] [100 Rem/Sv].

[B] Submersion Source Term = [MAR (Ci/canister)] [DCF(Sv-m³/Bq-s)] [3.7×10^{10} Bq/Ci] [100 Rem/Sv].

Table II-6. Plutonium Inhalation Dose Potential for 50-Metric-Ton Case								
	Rem/Canister							
Isotope	Gonad	Breast	Lung	R Marrow	B Surface	Thyroid	Remainder	Effective
Pu-238	5.80E+09	2.07E+05	6.63E+10	3.15E+10	3.94E+11	1.99E+05	1.45E+10	2.20E+10
Pu-239	1.83E+11	5.30E+06	1.86E+12	9.72E+11	1.21E+13	5.20E+06	4.35E+11	6.67E+11
Pu-240	4.75E+10	1.42E+06	4.83E+11	2.53E+11	3.15E+12	1.35E+06	1.13E+11	1.73E+11
Pu-241	6.76E+09	3.03E+05	3.15E+10	3.33E+10	4.16E+11	1.23E+05	1.30E+10	2.21E+10
Am-241	4.88E+10	4.01E+06	2.76E+10	2.61E+11	3.26E+12	1.59E+06	1.17E+11	1.80E+11
Pu-242	4.80E+06	1.50E+02	4.88E+07	2.56E+07	3.20E+08	1.40E+02	1.14E+07	1.77E+07
U-234	4.63E-01	4.63E-01	5.51E+03	1.29E+01	2.02E+02	4.63E-01	1.71E+01	6.62E+02
U-235	8.77E+01	8.81E+01	1.02E+06	2.43E+03	3.74E+04	8.77E+01	3.18E+03	1.23E+05
U-238	1.49E+03	1.49E+03	1.77E+07	4.38E+04	6.51E+05	1.48E+03	5.47E+04	2.13E+06
Th-232	8.46E+01	8.57E+01	1.04E+05	9.91E+04	1.23E+06	8.26E+01	2.08E+02	4.92E+04
Total	2.92E+11	1.12E+07	2.47E+12	1.55E+12	1.94E+13	8.46E+06	6.93E+11	1.07E+12

Table II-7. Plutonium Submersion Dose Potential for 50-Metric-Ton Case										
	$(Rem\text{-}m^3)/(s\text{-}Canister)$									
Isotope	Gonad	Breast	Lung	R Marrow	B Surface	Thyroid	Remainder	Effective	Skin	Lens Eye
Pu-238	1.36E-03	2.63E-03	2.20E-04	3.48E-04	1.93E-03	8.31E-04	4.12E-04	1.01E-03	8.47E-03	0.00E+00
Pu-239	2.78E-02	4.34E-02	1.52E-02	1.54E-02	5.45E-02	2.23E-02	1.65E-02	2.44E-02	1.07E-01	0.00E+00
Pu-240	9.51E-03	1.84E-02	1.63E-03	2.47E-03	1.38E-02	5.86E-03	2.93E-03	7.10E-03	5.86E-02	0.00E+00
Pu-241	7.13E-04	8.60E-04	6.43E-04	5.58E-04	2.17E-03	6.92E-04	6.04E-04	7.19E-04	1.16E-03	0.00E+00
Am-241	1.29E+00	1.61E+00	1.01E+00	7.83E-01	4.31E+00	1.18E+00	9.52E-01	1.23E+00	1.92E+00	0.00E+00
Pu-242	8.50E-07	1.64E-06	1.54E-07	2.28E-07	1.26E-06	5.28E-07	2.67E-07	6.38E-07	5.20E-06	0.00E+00
U-234	1.63E-10	2.66E-10	8.10E-11	7.77E-11	3.68E-10	1.24E-10	8.88E-11	1.41E-10	7.86E-10	0.00E+00
U-235	2.61E-05	3.00E-05	2.50E-05	2.28E-05	6.81E-05	2.61E-05	2.36E-05	2.66E-05	3.20E-05	0.00E+00
U-238	2.92E-07	5.69E-07	6.63E-08	8.26E-08	4.93E-07	1.81E-07	1.01E-07	2.27E-07	1.94E-06	0.00E+00
Th-232	1.04E-09	1.51E-09	7.07E-10	6.13E-10	2.89E-09	8.77E-10	7.04E-10	9.68E-10	3.82E-09	0.00E+00
Total	1.33E+00	1.67E+00	1.03E+00	8.01E-01	4.38E+00	1.21E+00	9.73E-01	1.26E+00	2.10E+00	0.00E+00

NOTES

[A] Inhalation Source Term = [MAR (Ci/canister)] [DCF(Sv/Bq)] [3.7×10^{10} Bq/Ci] [100 Rem/Sv].

[B] Submersion Source Term = [MAR (Ci/canister)] [DCF(Sv-m^3/Bq-s)] [3.7×10^{10} Bq/Ci] [100 Rem/Sv].

Table II-8. HLW Doses per HLW Canister (using expected LPF)										
Organ (1)	Inhalation Dose (for 264-inch drop) (rem) (12)*	Submersion Dose (for 264-inch drop) (rem) (13)*	X/Q Factor (50% acute) (14)	X/Q Factor (Max) (14a)	LPF (15)	Fraction of HLW in Canister (16)	Inhalation Dose (rem) (50% acute) (17)	Submersion Dose (rem) (50% acute) (18)	Inhalation Dose (rem) (Max X/Q) (19)	Submersion Dose (rem) (Max X/Q) (20)
Gonad	9.23E-02	6.79E-06	1.05E-01	4.64E-01	1.00E-01	8.80E-01	8.54E-04	6.28E-08	3.77E-03	2.77E-07
Breast	8.94E-04	7.75E-06	1.05E-01	4.64E-01	1.00E-01	8.80E-01	8.27E-06	7.17E-08	3.65E-05	3.16E-07
Lung	1.24E+00	6.73E-06	1.05E-01	4.64E-01	1.00E-01	8.80E-01	1.15E-02	6.23E-08	5.06E-02	2.75E-07
R Marrow	5.27E-01	6.56E-06	1.05E-01	4.64E-01	1.00E-01	8.80E-01	4.88E-03	6.07E-08	2.15E-02	2.68E-07
B Surface	6.26E+00	1.12E-05	1.05E-01	4.64E-01	1.00E-01	8.80E-01	5.79E-02	1.04E-07	2.55E-01	4.57E-07
Thyroid	8.93E-04	6.93E-06	1.05E-01	4.64E-01	1.00E-01	8.80E-01	8.26E-06	6.41E-08	3.64E-05	2.83E-07
Remainder	2.31E-01	6.45E-06	1.05E-01	4.64E-01	1.00E-01	8.80E-01	2.14E-03	5.97E-08	9.43E-03	2.63E-07
Effective	3.78E-01	6.93E-06	1.05E-01	4.64E-01	1.00E-01	8.80E-01	3.50E-03	6.41E-08	1.54E-02	2.83E-07
Skin	NA	3.03E-05	1.05E-01	4.64E-01	1.00E-01	8.80E-01	NA	2.80E-07	NA	1.24E-06
Lens of Eye	NA	0.00E+00	1.05E-01	4.64E-01	1.00E-01	8.80E-01	NA	0.00E+00	NA	0.00E+00

* Reference: CRWMS M&O 1999b, Page VIII-7 of VIII-7

(14) = 1.05E-01 X/Q Adjustment Factor = (50% acute X/Q)/(X/Q originally used in HLW Calc) = 4.92E-6/4.68E-5

(14a) = 4.64E-01 X/Q Adjustment Factor = (Max. X/Q)/(X/Q originally used in HLW Calc) = 2.17E-5/4.68E-5

(15) = 1.00E-01 LPF for HLW (Assumption 3.7)

(16) = 8.80E-01 Fraction of HLW used in adjusted HLW dose

Inhalation Calculation (50% acute X/Q)

(17) = (12) * (14) * (15) * (16)

Submersion Calculation (50% acute X/Q)

(18) = (13) * (14) * (15) * (16)

Inhalation Calculation (Max X/Q)

(19) = (12) * (14a) * (15) * (16)

Submersion Calculation (Max. X/Q & LPF)

(20) = (13) * (14a) * (15) * (16)

Table II-9. HLW Doses per HLW Canister (using most conservative LPF)										
Organ (1)	Inhalation Dose (for 264-inch drop) (rem) (12)*	Submersion Dose (for 264-inch drop) (rem) (13)*	X/Q Factor (50% acute) (14)	X/Q Factor (Max) (14a)	LPF (Conser-vative) (15a)	Fraction of HLW in Canister (16)	Inhalation Dose (rem) (50% acute & Max. LPF) (21)	Submersion Dose (rem) (50% acute & Max. LPF) (22)	Inhalation Dose (rem) (Max. X/Q & LPF) (23)	Submersion Dose (rem) (Max. X/Q & LPF) (24)
Gonad	9.23E-02	6.79E-06	1.05E-01	4.64E-01	1.00E+00	8.80E-01	8.54E-03	6.28E-07	3.77E-02	2.77E-06
Breast	8.94E-04	7.75E-06	1.05E-01	4.64E-01	1.00E+00	8.80E-01	8.27E-05	7.17E-07	3.65E-04	3.16E-06
Lung	1.24E+00	6.73E-06	1.05E-01	4.64E-01	1.00E+00	8.80E-01	1.15E-01	6.23E-07	5.06E-01	2.75E-06
R Marrow	5.27E-01	6.56E-06	1.05E-01	4.64E-01	1.00E+00	8.80E-01	4.88E-02	6.07E-07	2.15E-01	2.68E-06
B Surface	6.26E+00	1.12E-05	1.05E-01	4.64E-01	1.00E+00	8.80E-01	5.79E-01	1.04E-06	2.55E+00	4.57E-06
Thyroid	8.93E-04	6.93E-06	1.05E-01	4.64E-01	1.00E+00	8.80E-01	8.26E-05	6.41E-07	3.64E-04	2.83E-06
Remainder	2.31E-01	6.45E-06	1.05E-01	4.64E-01	1.00E+00	8.80E-01	2.14E-02	5.97E-07	9.43E-02	2.63E-06
Effective	3.78E-01	6.93E-06	1.05E-01	4.64E-01	1.00E+00	8.80E-01	3.50E-02	6.41E-07	1.54E-01	2.83E-06
Skin	NA	3.03E-05	1.05E-01	4.64E-01	1.00E+00	8.80E-01	NA	2.80E-06	NA	1.24E-05
Lens of Eye	NA	0.00E+00	1.05E-01	4.64E-01	1.00E+00	8.80E-01	NA	0.00E+00	NA	0.00E+00

* Reference: CRWMS M&O 1999b, Page VIII-7 of VIII-7

(14) = 1.05E-01 X/Q Adjustment Factor = (50% acute X/Q)/(X/Q originally used in HLW Calc) = 4.92E-6/4.68E-5

(14a) = 4.64E-01 X/Q Adjustment Factor = (Max. X/Q)/(X/Q originally used in HLW Calc) = 2.17E-5/4.68E-5

(15a) = 1.00E+00 Most Conservative LPF

(16) = 8.80E-01 Fraction of HLW used in adjusted HLW dose

Inhalation Calculation (50% acute X/Q)

(21) = (12) * (14) * (15a) * (16)

Submersion Calculation (50% acute X/Q)

(22) = (13) * (14) * (15a) * (16)

Inhalation Calculation (Max X/Q & LPF)

(23) = (12) * (14a) * (15a) * (16)

Submersion Calculation (Max. X/Q & LPF)

(24) = (13) * (14a) * (15a) * (16)

Table II-10. Unfiltered Offsite Inhalation Dose (using 50% Acute X/Q)										
Organ	Plutonium Dose**	DR	ARF x RF	LPF	Mitigation Factor	Breathing Rate	11-km 50% Acute X/Q	Dose due to Plutonium	Dose due to HLW*	Offsite 11-km Can Dose
	(rem/can)	(-)	(-)	(-)	(-)	(m^3/sec)	(sec/m^3)	(rem)	(rem)	(rem)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Gonad	3.44E+11	2.50E-01	3.00E-04	1.00E-02	1	3.33E-04	4.92E-06	4.22E-04	8.54E-04	1.28E-03
Breast	1.46E+07	2.50E-01	3.00E-04	1.00E-02	1	3.33E-04	4.92E-06	1.79E-08	8.27E-06	8.29E-06
Lung	2.67E+12	2.50E-01	3.00E-04	1.00E-02	1	3.33E-04	4.92E-06	3.28E-03	1.15E-02	1.47E-02
R Marrow	1.83E+12	2.50E-01	3.00E-04	1.00E-02	1	3.33E-04	4.92E-06	2.24E-03	4.88E-03	7.12E-03
B Surface	2.28E+13	2.50E-01	3.00E-04	1.00E-02	1	3.33E-04	4.92E-06	2.80E-02	5.79E-02	**8.59E-02**
Thyroid	1.01E+07	2.50E-01	3.00E-04	1.00E-02	1	3.33E-04	4.92E-06	1.24E-08	8.26E-06	8.27E-06
Remainder	8.16E+11	2.50E-01	3.00E-04	1.00E-02	1	3.33E-04	4.92E-06	1.00E-03	2.14E-03	3.14E-03
Effective	1.25E+12	2.50E-01	3.00E-04	1.00E-02	1	3.33E-04	4.92E-06	1.54E-03	3.50E-03	**5.04E-03**

* From Table II-8.

** From Table II-4.

Table II-11. Unfiltered Offsite Submersion Dose (using 50% Acute X/Q)									
Organ	Plutonium Dose**	DR	ARF	LPF	Mitigation Factor	11-km 50% Acute X/Q	Dose due to Plutonium	Dose due to HLW*	Offsite 11-km Can Dose
	(rem-m^3/s-can)	(-)	(-)	(-)	(-)	(sec/m^3)	(rem)	(rem)	(rem)
(1)	(2)	(3)	(4)	(5)	(6)	(8)	(9)	(10)	(11)
Gonad	2.19E+00	2.50E-01	3.00E-04	1.00E-02	1	4.92E-06	8.07E-12	6.28E-08	6.28E-08
Breast	2.75E+00	2.50E-01	3.00E-04	1.00E-02	1	4.92E-06	1.01E-11	7.17E-08	7.17E-08
Lung	1.70E+00	2.50E-01	3.00E-04	1.00E-02	1	4.92E-06	6.28E-12	6.23E-08	6.23E-08
R Marrow	1.32E+00	2.50E-01	3.00E-04	1.00E-02	1	4.92E-06	4.87E-12	6.07E-08	6.07E-08
B Surface	7.25E+00	2.50E-01	3.00E-04	1.00E-02	1	4.92E-06	2.67E-11	1.04E-07	**1.04E-07**
Thyroid	1.99E+00	2.50E-01	3.00E-04	1.00E-02	1	4.92E-06	7.33E-12	6.41E-08	6.41E-08
Remainder	1.61E+00	2.50E-01	3.00E-04	1.00E-02	1	4.92E-06	5.92E-12	5.97E-08	5.97E-08
Effective	2.08E+00	2.50E-01	3.00E-04	1.00E-02	1	4.92E-06	7.67E-12	6.41E-08	**6.41E-08**
Skin	3.40E+00	2.50E-01	3.00E-04	1.00E-02	1	4.92E-06	1.25E-11	2.80E-07	**2.80E-07**
Lens of Eye	0.00E+00	2.50E-01	3.00E-04	1.00E-02	1	4.92E-06	0.00E+00	0.00E+00	**0.00E+00**

* From Table II-8.

** From Table II-5.

Continuation from Previous Page

Inhalation

(9) = (2) x (3) x (4) x (5) x (6) x (7) x (8)

(10) = Value from Table II-8

(11) = (9) + (10)

Submersion

(9) = (2) x (3) x (4) x (5) x (6) x (8)

(10) = Value from Table II-8

(11) = (9) + (10)

w/o HEPAs	11 km
Dose	(rem)
CEDE	5.04E-03
DDE (eff.)	6.41E-08
TEDE	5.04E-03
CDE (max)	8.59E-02
CDE + DDE	8.59E-02
Lens of Eye	5.04E-03
Skin	2.80E-07

CEDE, DDE, CDE, TEDE Dose Table

CEDE = (11) for effective organ with inhalation

DDE = (11) for effective organ with submersion

TEDE = CEDE + DDE

CDE = (11) for maximum organ with inhalation

Lens of Eye = Skin + TEDE

Table II-12. Filtered Offsite Inhalation Dose (using 50% Acute X/Q)										
Organ	Plutonium Dose** (rem/can)	DR (-)	ARF x RF (-)	LPF (-)	Mitigation Factor (-)	Breathing Rate (m^3/sec)	11-km 50% Acute X/Q (sec/m^3)	Dose due to Plutonium (rem)	Dose due to HLW* (rem)	Offsite 11-km Can Dose (rem)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Gonad	3.44E+11	2.50E-01	3.00E-04	1.00E-02	3.00E-04	3.33E-04	4.92E-06	1.27E-07	2.56E-07	3.83E-07
Breast	1.46E+07	2.50E-01	3.00E-04	1.00E-02	3.00E-04	3.33E-04	4.92E-06	5.38E-12	2.48E-09	2.49E-09
Lung	2.67E+12	2.50E-01	3.00E-04	1.00E-02	3.00E-04	3.33E-04	4.92E-06	9.83E-07	3.44E-06	4.42E-06
R Marrow	1.83E+12	2.50E-01	3.00E-04	1.00E-02	3.00E-04	3.33E-04	4.92E-06	6.73E-07	1.46E-06	2.14E-06
B Surface	2.28E+13	2.50E-01	3.00E-04	1.00E-02	3.00E-04	3.33E-04	4.92E-06	8.40E-06	1.74E-05	**2.58E-05**
Thyroid	1.01E+07	2.50E-01	3.00E-04	1.00E-02	3.00E-04	3.33E-04	4.92E-06	3.71E-12	2.48E-09	2.48E-09
Remainder	8.16E+11	2.50E-01	3.00E-04	1.00E-02	3.00E-04	3.33E-04	4.92E-06	3.01E-07	6.41E-07	9.42E-07
Effective	1.25E+12	2.50E-01	3.00E-04	1.00E-02	3.00E-04	3.33E-04	4.92E-06	4.62E-07	1.05E-06	**1.51E-06**

* From Table II-8.

** From Table II-4.

Table II-13. Filtered Offsite Submersion Dose (using 50% Acute X/Q)									
Organ	Plutonium Dose** (rem-m^3/s-can)	DR (-)	ARF (-)	LPF (-)	Mitigation Factor (-)	11-km 50% Acute X/Q (sec/m^3)	Dose due to Plutonium (rem)	Dose due to HLW* (rem)	Offsite 11-km Can Dose (rem)
(1)	(2)	(3)	(4)	(5)	(6)	(8)	(9)	(10)	(11)
Gonad	2.19E+00	2.50E-01	3.00E-04	1.00E-02	3.00E-04	4.92E-06	2.42E-15	1.88E-11	1.88E-11
Breast	2.75E+00	2.50E-01	3.00E-04	1.00E-02	3.00E-04	4.92E-06	3.04E-15	2.15E-11	2.15E-11
Lung	1.70E+00	2.50E-01	3.00E-04	1.00E-02	3.00E-04	4.92E-06	1.88E-15	1.87E-11	1.87E-11
R Marrow	1.32E+00	2.50E-01	3.00E-04	1.00E-02	3.00E-04	4.92E-06	1.46E-15	1.82E-11	1.82E-11
B Surface	7.25E+00	2.50E-01	3.00E-04	1.00E-02	3.00E-04	4.92E-06	8.02E-15	3.11E-11	**3.11E-11**
Thyroid	1.99E+00	2.50E-01	3.00E-04	1.00E-02	3.00E-04	4.92E-06	2.20E-15	1.92E-11	1.92E-11
Remainder	1.61E+00	2.50E-01	3.00E-04	1.00E-02	3.00E-04	4.92E-06	1.78E-15	1.79E-11	1.79E-11
Effective	2.08E+00	2.50E-01	3.00E-04	1.00E-02	3.00E-04	4.92E-06	2.30E-15	1.92E-11	**1.92E-11**
Skin	3.40E+00	2.50E-01	3.00E-04	1.00E-02	3.00E-04	4.92E-06	3.76E-15	8.41E-11	**8.41E-11**
Lens of Eye	0.00E+00	2.50E-01	3.00E-04	1.00E-02	3.00E-04	4.92E-06	0.00E+00	0.00E+00	**0.00E+00**

* From Table II-8.

** From Table II-5.

Continuation from Previous Page

Inhalation

(9) = (2) x (3) x (4) x (5) x (6) x (7) x (8)

(10) = (Value from Table II-8) • (6)

(11) = (9) + (10)

Submersion

(9) = (2) x (3) x (4) x (5) x (6) x (8)

(10) = (Value from Table II-8) • (6)

(11) = (9) + (10)

with HEPAs	11 km
Dose	(rem)
CEDE	1.51E-06
DDE (eff.)	1.92E-11
TEDE	1.51E-06
CDE (max)	2.58E-05
CDE + DDE	2.58E-05
Lens of Eye	1.51E-06
Skin	8.41E-11

CEDE, DDE, CDE, TEDE Dose Table

CEDE = (11) for effective organ with inhalation

DDE = (11) for effective organ with submersion

TEDE ■ CEDE + DDE

CDE = (11) for maximum organ with inhalation

Lens of Eye = Skin + TEDE

Table II-14. Unfiltered Offsite Inhalation Dose (using Maximum Acute X/Q)										
Organ	Plutonium Dose**	DR	ARF x RF	LPF	Mitigation Factor	Breathing Rate	11-km Max. Acute X/Q	Dose due to Plutonium	Dose due to HLW*	Offsite 11-km Can Dose
	(rem/can)	(-)	(-)	(-)	(-)	(m^3/sec)	(sec/m^3)	(rem)	(rem)	(rem)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Gonad	3.44E+11	2.50E-01	3.00E-04	1.00E-02	1	3.33E-04	2.17E-05	1.86E-03	3.77E-03	5.63E-03
Breast	1.46E+07	2.50E-01	3.00E-04	1.00E-02	1	3.33E-04	2.17E-05	7.91E-08	3.65E-05	3.66E-05
Lung	2.67E+12	2.50E-01	3.00E-04	1.00E-02	1	3.33E-04	2.17E-05	1.44E-02	5.06E-02	6.50E-02
R Marrow	1.83E+12	2.50E-01	3.00E-04	1.00E-02	1	3.33E-04	2.17E-05	9.90E-03	2.15E-02	3.14E-02
B Surface	2.28E+13	2.50E-01	3.00E-04	1.00E-02	1	3.33E-04	2.17E-05	1.24E-01	2.55E-01	**3.79E-01**
Thyroid	1.01E+07	2.50E-01	3.00E-04	1.00E-02	1	3.33E-04	2.17E-05	5.45E-08	3.64E-05	3.65E-05
Remainder	8.16E+11	2.50E-01	3.00E-04	1.00E-02	1	3.33E-04	2.17E-05	4.42E-03	9.43E-03	1.38E-02
Effective	1.25E+12	2.50E-01	3.00E-04	1.00E-02	1	3.33E-04	2.17E-05	6.80E-03	1.54E-02	**2.22E-02**

* From Table II-8.

** From Table II-4.

Table II-15. Unfiltered Offsite Submersion Dose (using Maximum Acute X/Q)									
Organ	Plutonium Dose**	DR	ARF	LPF	Mitigation Factor	11-km Max. Acute X/Q	Dose due to Plutonium	Dose due to HLW*	Offsite 11-km Can Dose
	(rem-m^3/s-can)	(-)	(-)	(-)	(-)	(sec/m^3)	(rem)	(rem)	(rem)
(1)	(2)	(3)	(4)	(5)	(6)	(8)	(9)	(10)	(11)
Gonad	2.19E+00	2.50E-01	3.00E-04	1.00E-02	1	2.17E-05	3.56E-11	2.77E-07	2.77E-07
Breast	2.75E+00	2.50E-01	3.00E-04	1.00E-02	1	2.17E-05	4.47E-11	3.16E-07	3.16E-07
Lung	1.70E+00	2.50E-01	3.00E-04	1.00E-02	1	2.17E-05	2.77E-11	2.75E-07	2.75E-07
R Marrow	1.32E+00	2.50E-01	3.00E-04	1.00E-02	1	2.17E-05	2.15E-11	2.68E-07	2.68E-07
B Surface	7.25E+00	2.50E-01	3.00E-04	1.00E-02	1	2.17E-05	1.18E-10	4.57E-07	**4.57E-07**
Thyroid	1.99E+00	2.50E-01	3.00E-04	1.00E-02	1	2.17E-05	3.24E-11	2.83E-07	2.83E-07
Remainder	1.61E+00	2.50E-01	3.00E-04	1.00E-02	1	2.17E-05	2.61E-11	2.63E-07	2.63E-07
Effective	2.08E+00	2.50E-01	3.00E-04	1.00E-02	1	2.17E-05	3.38E-11	2.83E-07	**2.83E-07**
Skin	3.40E+00	2.50E-01	3.00E-04	1.00E-02	1	2.17E-05	5.53E-11	1.24E-06	**1.24E-06**
Lens of Eye	0.00E+00	2.50E-01	3.00E-04	1.00E-02	1	2.17E-05	0.00E+00	0.00E+00	**0.00E+00**

* From Table II-8.

** From Table II-5.

Continuation from Previous Page

Inhalation

(9) = (2) x (3) x (4) x (5) x (6) x (7) x (8)

(10) = Value from Table II-8

(11) = (9) + (10)

Submersion

(9) = (2) x (3) x (4) x (5) x (6) x (8)

(10) = Value from Table II-8

(11) = (9) + (10)

w/o HEPAs	11 km
Dose	(rem)
CEDE	2.22E-02
DDE (eff.)	2.83E-07
TEDE	2.22E-02
CDE (max)	3.79E-01
CDE + DDE	3.79E-01
Lens of Eye	2.22E-02
Skin	1.24E-06

CEDE, DDE, CDE, TEDE Dose Table

CEDE = (11) for effective organ with inhalation

DDE = (11) for effective organ with submersion

TEDE = CEDE + DDE

CDE = (11) for maximum organ with inhalation

Lens of Eye = Skin + TEDE

Table II-16. Filtered Offsite Inhalation Dose (using Maximum Acute X/Q)										
Organ	Plutonium Dose**	DR	ARF x RF	LPF	Mitigation Factor	Breathing Rate	11-km Max. Acute X/Q	Dose due to Plutonium	Dose due to HLW*	Offsite 11-km Can Dose
	(rem/can)	(-)	(-)	(-)	(-)	(m^3/sec)	(sec/m^3)	(rem)	(rem)	(rem)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Gonad	3.44E+11	2.50E-01	3.00E-04	1.00E-02	3.00E-04	3.33E-04	2.17E-05	5.59E-07	1.13E-06	1.69E-06
Breast	1.46E+07	2.50E-01	3.00E-04	1.00E-02	3.00E-04	3.33E-04	2.17E-05	2.37E-11	1.09E-08	1.10E-08
Lung	2.67E+12	2.50E-01	3.00E-04	1.00E-02	3.00E-04	3.33E-04	2.17E-05	4.33E-06	1.52E-05	1.95E-05
R Marrow	1.83E+12	2.50E-01	3.00E-04	1.00E-02	3.00E-04	3.33E-04	2.17E-05	2.97E-06	6.45E-06	9.42E-06
B Surface	2.28E+13	2.50E-01	3.00E-04	1.00E-02	3.00E-04	3.33E-04	2.17E-05	3.71E-05	7.66E-05	**1.14E-04**
Thyroid	1.01E+07	2.50E-01	3.00E-04	1.00E-02	3.00E-04	3.33E-04	2.17E-05	1.64E-11	1.09E-08	1.09E-08
Remainder	8.16E+11	2.50E-01	3.00E-04	1.00E-02	3.00E-04	3.33E-04	2.17E-05	1.33E-06	2.83E-06	4.15E-06
Effective	1.25E+12	2.50E-01	3.00E-04	1.00E-02	3.00E-04	3.33E-04	2.17E-05	2.04E-06	4.63E-06	**6.67E-06**

* From Table II-8.

** From Table II-4.

Table II-17. Filtered Offsite Submersion Dose (using Maximum Acute X/Q)									
Organ	Plutonium Dose**	DR	ARF	LPF	Mitigation Factor	11-km Max. Acute X/Q	Dose due to Plutonium	Dose due to HLW*	Offsite 11-km Can Dose
	(rem-m^3/s-can)	(-)	(-)	(-)	(-)	(sec/m^3)	(rem)	(rem)	(rem)
(1)	(2)	(3)	(4)	(5)	(6)	(8)	(9)	(10)	(11)
Gonad	2.19E+00	2.50E-01	3.00E-04	1.00E-02	3.00E-04	2.17E-05	1.07E-14	8.31E-11	8.31E-11
Breast	2.75E+00	2.50E-01	3.00E-04	1.00E-02	3.00E-04	2.17E-05	1.34E-14	9.49E-11	9.49E-11
Lung	1.70E+00	2.50E-01	3.00E-04	1.00E-02	3.00E-04	2.17E-05	8.31E-15	8.24E-11	8.24E-11
R Marrow	1.32E+00	2.50E-01	3.00E-04	1.00E-02	3.00E-04	2.17E-05	6.45E-15	8.03E-11	8.03E-11
B Surface	7.25E+00	2.50E-01	3.00E-04	1.00E-02	3.00E-04	2.17E-05	3.54E-14	1.37E-10	**1.37E-10**
Thyroid	1.99E+00	2.50E-01	3.00E-04	1.00E-02	3.00E-04	2.17E-05	9.71E-15	8.48E-11	8.48E-11
Remainder	1.61E+00	2.50E-01	3.00E-04	1.00E-02	3.00E-04	2.17E-05	7.84E-15	7.90E-11	7.90E-11
Effective	2.08E+00	2.50E-01	3.00E-04	1.00E-02	3.00E-04	2.17E-05	1.02E-14	8.48E-11	**8.48E-11**
Skin	3.40E+00	2.50E-01	3.00E-04	1.00E-02	3.00E-04	2.17E-05	1.66E-14	3.71E-10	**3.71E-10**
Lens of Eye	0.00E+00	2.50E-01	3.00E-04	1.00E-02	3.00E-04	2.17E-05	0.00E+00	0.00E+00	**0.00E+00**

* From Table II-8.

** From Table II-5.

Continuation from Previous Page

Inhalation

(9) = (2) x (3) x (4) x (5) x (6) x (7) x (8)

(10) = (Value from Table II-8) * (6)

(11) = (9) + (10)

Submersion

(9) = (2) x (3) x (4) x (5) x (6) x (8)

(10) = (Value from Table II-8) * (6)

(11) = (9) + (10)

with HEPAs	11 km
Dose	(rem)
CEDE	6.67E-06
DDE (eff.)	8.48E-11
TEDE	6.67E-06
CDE (max)	1.14E-04
CDE + DDE	1.14E-04
Lens of Eye	6.67E-06
Skin	3.71E-10

CEDE, DDE, CDE, TEDE Dose Table

CEDE = (11) for effective organ with inhalation

DDE = (11) for effective organ with submersion

TEDE = CEDE + DDE

CDE = (11) for maximum organ with inhalation

Lens of Eye = Skin + TEDE

Table II-18. Unfiltered Offsite Inhalation Dose (using 50% Acute X/Q and Conservative LPF)										
	Plutonium Dose**	DR	ARF x RF	LPF	Mitigation Factor	Breathing Rate	11-km 50% Acute X/Q	Dose due to Plutonium	Dose due to HLW*	Offsite 11-km Can Dose
Organ	(rem/can)	(-)	(-)	(-)	(-)	(m^3/sec)	(sec/m^3)	(rem)	(rem)	(rem)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Gonad	3.44E+11	2.50E-01	3.00E-04	1.00E+00	1	3.33E-04	4.92E-06	4.22E-02	8.54E-03	5.08E-02
Breast	1.46E+07	2.50E-01	3.00E-04	1.00E+00	1	3.33E-04	4.92E-06	1.79E-06	8.27E-05	8.45E-05
Lung	2.67E+12	2.50E-01	3.00E-04	1.00E+00	1	3.33E-04	4.92E-06	3.28E-01	1.15E-01	4.42E-01
R Marrow	1.83E+12	2.50E-01	3.00E-04	1.00E+00	1	3.33E-04	4.92E-06	2.24E-01	4.88E-02	2.73E-01
B Surface	2.28E+13	2.50E-01	3.00E-04	1.00E+00	1	3.33E-04	4.92E-06	2.80E+00	5.79E-01	**3.38E+00**
Thyroid	1.01E+07	2.50E-01	3.00E-04	1.00E+00	1	3.33E-04	4.92E-06	1.24E-06	8.26E-05	8.39E-05
Remainder	8.16E+11	2.50E-01	3.00E-04	1.00E+00	1	3.33E-04	4.92E-06	1.00E-01	2.14E-02	1.22E-01
Effective	1.25E+12	2.50E-01	3.00E-04	1.00E+00	1	3.33E-04	4.92E-06	1.54E-01	3.50E-02	**1.89E-01**

* From Table II-9.

** From Table II-4.

Table II-19. Unfiltered Offsite Submersion Dose (using 50% Acute X/Q and Conservative LPF)									
	Plutonium Dose**	DR	ARF	LPF	Mitigation Factor	11-km 50% Acute X/Q	Dose due to Plutonium	Dose due to HLW*	Offsite 11-km Can Dose
Organ	(rem-m^3/s-can)	(-)	(-)	(-)	(-)	(sec/m^3)	(rem)	(rem)	(rem)
(1)	(2)	(3)	(4)	(5)	(6)	(8)	(9)	(10)	(11)
Gonad	2.19E+00	2.50E-01	3.00E-04	1.00E+00	1	4.92E-06	8.07E-10	6.28E-07	6.29E-07
Breast	2.75E+00	2.50E-01	3.00E-04	1.00E+00	1	4.92E-06	1.01E-09	7.17E-07	7.18E-07
Lung	1.70E+00	2.50E-01	3.00E-04	1.00E+00	1	4.92E-06	6.28E-10	6.23E-07	6.23E-07
R Marrow	1.32E+00	2.50E-01	3.00E-04	1.00E+00	1	4.92E-06	4.87E-10	6.07E-07	6.07E-07
B Surface	7.25E+00	2.50E-01	3.00E-04	1.00E+00	1	4.92E-06	2.67E-09	1.04E-06	**1.04E-06**
Thyroid	1.99E+00	2.50E-01	3.00E-04	1.00E+00	1	4.92E-06	7.33E-10	6.41E-07	6.42E-07
Remainder	1.61E+00	2.50E-01	3.00E-04	1.00E+00	1	4.92E-06	5.92E-10	5.97E-07	5.97E-07
Effective	2.08E+00	2.50E-01	3.00E-04	1.00E+00	1	4.92E-06	7.67E-10	6.41E-07	**6.42E-07**
Skin	3.40E+00	2.50E-01	3.00E-04	1.00E+00	1	4.92E-06	1.25E-09	2.80E-06	**2.80E-06**
Lens of Eye	0.00E+00	2.50E-01	3.00E-04	1.00E+00	1	4.92E-06	0.00E+00	0.00E+00	**0.00E+00**

* From Table II-9.

** From Table II-5.

Continuation from Previous Page

Inhalation

(9) = (2) x (3) x (4) x (5) x (6) x (7) x (8)

(10) = Value from Table II-9

(11) = (9) + (10)

Submersion

(9) = (2) x (3) x (4) x (5) x (6) x (8)

(10) = Value from Table II-9

(11) = (9) + (10)

w/o HEPAs	11 km
Dose	(rem)
CEDE	1.89E-01
DDE (eff.)	6.42E-07
TEDE	1.89E-01
CDE (max)	3.38E+00
CDE + DDE	3.38E+00
Lens of Eye	1.89E-01
Skin	2.80E-06

CEDE, DDE, CDE, TEDE Dose Table

CEDE = (11) for effective organ with inhalation

DDE = (11) for effective organ with submersion

TEDE = CEDE + DDE

CDE = (11) for maximum organ with inhalation

Lens of Eye = Skin + TEDE

Table II-20. Filtered Offsite Inhalation Dose (using 50% Acute X/Q and Conservative LPF)										
Organ	Plutonium Dose** (rem/can)	DR (-)	ARF x RF (-)	LPF (-)	Mitigation Factor (-)	Breathing Rate (m^3/sec)	11-km 50% Acute X/Q (sec/m^3)	Dose due to Plutonium (rem)	Dose due to HLW* (rem)	Offsite 11-km Can Dose (rem)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Gonad	3.44E+11	2.50E-01	3.00E-04	1.00E+00	3.00E-04	3.33E-04	4.92E-06	1.27E-05	2.56E-06	1.52E-05
Breast	1.46E+07	2.50E-01	3.00E-04	1.00E+00	3.00E-04	3.33E-04	4.92E-06	5.38E-10	2.48E-08	2.53E-08
Lung	2.67E+12	2.50E-01	3.00E-04	1.00E+00	3.00E-04	3.33E-04	4.92E-06	9.83E-05	3.44E-05	1.33E-04
R Marrow	1.83E+12	2.50E-01	3.00E-04	1.00E+00	3.00E-04	3.33E-04	4.92E-06	6.73E-05	1.46E-05	8.20E-05
B Surface	2.28E+13	2.50E-01	3.00E-04	1.00E+00	3.00E-04	3.33E-04	4.92E-06	8.40E-04	1.74E-04	**1.01E-03**
Thyroid	1.01E+07	2.50E-01	3.00E-04	1.00E+00	3.00E-04	3.33E-04	4.92E-06	3.71E-10	2.48E-08	2.52E-08
Remainder	8.16E+11	2.50E-01	3.00E-04	1.00E+00	3.00E-04	3.33E-04	4.92E-06	3.01E-05	6.41E-06	3.65E-05
Effective	1.25E+12	2.50E-01	3.00E-04	1.00E+00	3.00E-04	3.33E-04	4.92E-06	4.62E-05	1.05E-05	**5.67E-05**

* From Table II-9.

** From Table II-4.

Table II-21. Filtered Offsite Submersion Dose (using 50% Acute X/Q and Conservative LPF)									
Organ	Plutonium Dose** (rem-m^3/s-can)	DR (-)	ARF (-)	LPF (-)	Mitigation Factor (-)	11-km 50% Acute X/Q (sec/m^3)	Dose due to Plutonium (rem)	Dose due to HLW* (rem)	Offsite 11-km Can Dose (rem)
(1)	(2)	(3)	(4)	(5)	(6)	(8)	(9)	(10)	(11)
Gonad	2.19E+00	2.50E-01	3.00E-04	1.00E+00	3.00E-04	4.92E-06	2.42E-13	1.88E-10	1.89E-10
Breast	2.75E+00	2.50E-01	3.00E-04	1.00E+00	3.00E-04	4.92E-06	3.04E-13	2.15E-10	2.15E-10
Lung	1.70E+00	2.50E-01	3.00E-04	1.00E+00	3.00E-04	4.92E-06	1.88E-13	1.87E-10	1.87E-10
R Marrow	1.32E+00	2.50E-01	3.00E-04	1.00E+00	3.00E-04	4.92E-06	1.46E-13	1.82E-10	1.82E-10
B Surface	7.25E+00	2.50E-01	3.00E-04	1.00E+00	3.00E-04	4.92E-06	8.02E-13	3.11E-10	**3.12E-10**
Thyroid	1.99E+00	2.50E-01	3.00E-04	1.00E+00	3.00E-04	4.92E-06	2.20E-13	1.92E-10	1.93E-10
Remainder	1.61E+00	2.50E-01	3.00E-04	1.00E+00	3.00E-04	4.92E-06	1.78E-13	1.79E-10	1.79E-10
Effective	2.08E+00	2.50E-01	3.00E-04	1.00E+00	3.00E-04	4.92E-06	2.30E-13	1.92E-10	**1.93E-10**
Skin	3.40E+00	2.50E-01	3.00E-04	1.00E+00	3.00E-04	4.92E-06	3.76E-13	8.41E-10	**8.41E-10**
Lens of Eye	0.00E+00	2.50E-01	3.00E-04	1.00E+00	3.00E-04	4.92E-06	0.00E+00	0.00E+00	**0.00E+00**

* From Table II-9.

** From Table II-5.

Continuation from Previous Page

Inhalation

(9) = (2) x (3) x (4) x (5) x (6) x (7) x (8)

(10) = (Value from Table II-9) • (6)

(11) = (9) + (10)

Submersion

(9) = (2) x (3) x (4) x (5) x (6) x (8)

(10) □ (Value from Table II-9) • (6)

(11) = (9) + (10)

with HEPAs	11 km
Dose	(rem)
CEDE	5.67E-05
DDE (eff.)	1.93E-10
TEDE	5.67E-05
CDE (max)	1.01E-03
CDE + DDE	1.01E-03
Lens of Eye	5.67E-05
Skin	8.41E-10

CEDE, DDE, CDE, TEDE Dose Table

CEDE = (11) for effective organ with inhalation

DDE = (11) for effective organ with submersion

TEDE = CEDE + DDE

CDE □ (11) for maximum organ with inhalation

Lens of Eye = Skin + TEDE

Table II-22. Unfiltered Offsite Inhalation Dose (using Maximum Acute X/Q and Conservative LPF)										
	Plutonium Dose**	DR	ARF x RF	LPF	Mitigation Factor	Breathing Rate	11-km Max. Acute X/Q	Dose due to Plutonium	Dose due to HLW*	Offsite 11-km Can Dose
Organ	(rem/can)	(-)	(-)	(-)	(-)	(m^3/sec)	(sec/m^3)	(rem)	(rem)	(rem)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Gonad	3.44E+11	2.50E-01	3.00E-04	1.00E+00	1	3.33E-04	2.17E-05	1.86E-01	3.77E-02	2.24E-01
Breast	1.46E+07	2.50E-01	3.00E-04	1.00E+00	1	3.33E-04	2.17E-05	7.91E-06	3.65E-04	3.73E-04
Lung	2.67E+12	2.50E-01	3.00E-04	1.00E+00	1	3.33E-04	2.17E-05	1.44E+00	5.06E-01	1.95E+00
R Marrow	1.83E+12	2.50E-01	3.00E-04	1.00E+00	1	3.33E-04	2.17E-05	9.90E-01	2.15E-01	1.20E+00
B Surface	2.28E+13	2.50E-01	3.00E-04	1.00E+00	1	3.33E-04	2.17E-05	1.24E+01	2.55E+00	**1.49E+01**
Thyroid	1.01E+07	2.50E-01	3.00E-04	1.00E+00	1	3.33E-04	2.17E-05	5.45E-06	3.64E-04	3.70E-04
Remainder	8.16E+11	2.50E-01	3.00E-04	1.00E+00	1	3.33E-04	2.17E-05	4.42E-01	9.43E-02	5.36E-01
Effective	1.25E+12	2.50E-01	3.00E-04	1.00E+00	1	3.33E-04	2.17E-05	6.80E-01	1.54E-01	**8.34E-01**

* From Table II-9.

** From Table II-4.

Table II-23. Unfiltered Offsite Submersion Dose (using Maximum Acute X/Q and Conservative LPF)									
	Plutonium Dose**	DR	ARF	LPF	Mitigation Factor	11-km Max. Acute X/Q	Dose due to Plutonium	Dose due to HLW*	Offsite 11-km Can Dose
Organ	(rem-m^3/s-can)	(-)	(-)	(-)	(-)	(sec/m^3)	(rem)	(rem)	(rem)
(1)	(2)	(3)	(4)	(5)	(6)	(8)	(9)	(10)	(11)
Gonad	2.19E+00	2.50E-01	3.00E-04	1.00E+00	1	2.17E-05	3.56E-09	2.77E-06	2.77E-06
Breast	2.75E+00	2.50E-01	3.00E-04	1.00E+00	1	2.17E-05	4.47E-09	3.16E-06	3.17E-06
Lung	1.70E+00	2.50E-01	3.00E-04	1.00E+00	1	2.17E-05	2.77E-09	2.75E-06	2.75E-06
R Marrow	1.32E+00	2.50E-01	3.00E-04	1.00E+00	1	2.17E-05	2.15E-09	2.68E-06	2.68E-06
B Surface	7.25E+00	2.50E-01	3.00E-04	1.00E+00	1	2.17E-05	1.18E-08	4.57E-06	**4.58E-06**
Thyroid	1.99E+00	2.50E-01	3.00E-04	1.00E+00	1	2.17E-05	3.24E-09	2.83E-06	2.83E-06
Remainder	1.61E+00	2.50E-01	3.00E-04	1.00E+00	1	2.17E-05	2.61E-09	2.63E-06	2.63E-06
Effective	2.08E+00	2.50E-01	3.00E-04	1.00E+00	1	2.17E-05	3.38E-09	2.83E-06	**2.83E-06**
Skin	3.40E+00	2.50E-01	3.00E-04	1.00E+00	1	2.17E-05	5.53E-09	1.24E-05	**1.24E-05**
Lens of Eye	0.00E+00	2.50E-01	3.00E-04	1.00E+00	1	2.17E-05	0.00E+00	0.00E+00	**0.00E+00**

* From Table II-9.

** From Table II-5.

Continuation from Previous Page

Inhalation

(9) = (2) x (3) x (4) x (5) x (6) x (7) x (8)

(10) = Value from Table II-9

(11) = (9) + (10)

Submersion

(9) = (2) x (3) x (4) x (5) x (6) x (8)

(10) = Value from Table II-9

(11) = (9) + (10)

w/o HEPAs	11 km
Dose	(rem)
CEDE	8.34E-01
DDE (eff.)	2.83E-06
TEDE	8.34E-01
CDE (max)	1.49E+01
CDE + DDE	1.49E+01
Lens of Eye	8.34E-01
Skin	1.24E-05

CEDE, DDE, CDE, TEDE Dose Table

CEDE = (11) for effective organ with inhalation

DDE = (11) for effective organ with submersion

TEDE = CEDE + DDE

CDE = (11) for maximum organ with inhalation

Lens of Eye = Skin + TEDE

Table II-24. Filtered Offsite Inhalation Dose (using Maximum Acute X/Q and Conservative LPF)										
Organ	Plutonium Dose** (rem/can)	DR (-)	ARF x RF (-)	LPF (-)	Mitigation Factor (-)	Breathing Rate (m^3/sec)	11-km Max. Acute X/Q (sec/m^3)	Dose due to Plutonium (rem)	Dose due to HLW* (rem)	Offsite 11-km Can Dose (rem)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Gonad	3.44E+11	2.50E-01	3.00E-04	1.00E+00	3.00E-04	3.33E-04	2.17E-05	5.59E-05	1.13E-05	6.72E-05
Breast	1.46E+07	2.50E-01	3.00E-04	1.00E+00	3.00E-04	3.33E-04	2.17E-05	2.37E-09	1.09E-07	1.12E-07
Lung	2.67E+12	2.50E-01	3.00E-04	1.00E+00	3.00E-04	3.33E-04	2.17E-05	4.33E-04	1.52E-04	5.85E-04
R Marrow	1.83E+12	2.50E-01	3.00E-04	1.00E+00	3.00E-04	3.33E-04	2.17E-05	2.97E-04	6.45E-05	3.61E-04
B Surface	2.28E+13	2.50E-01	3.00E-04	1.00E+00	3.00E-04	3.33E-04	2.17E-05	3.71E-03	7.66E-04	**4.47E-03**
Thyroid	1.01E+07	2.50E-01	3.00E-04	1.00E+00	3.00E-04	3.33E-04	2.17E-05	1.64E-09	1.09E-07	1.11E-07
Remainder	8.16E+11	2.50E-01	3.00E-04	1.00E+00	3.00E-04	3.33E-04	2.17E-05	1.33E-04	2.83E-05	1.61E-04
Effective	1.25E+12	2.50E-01	3.00E-04	1.00E+00	3.00E-04	3.33E-04	2.17E-05	2.04E-04	4.63E-05	**2.50E-04**

* From Table II-9.

** From Table II-4.

Table II-25. Filtered Offsite Submersion Dose (using Maximum Acute X/Q and Conservative LPF)									
Organ	Plutonium Dose** (rem-m^3/s-can)	DR (-)	ARF (-)	LPF (-)	Mitigation Factor (-)	11-km Max. Acute X/Q (sec/m^3)	Dose due to Plutonium (rem)	Dose due to HLW* (rem)	Offsite 11-km Can Dose (rem)
(1)	(2)	(3)	(4)	(5)	(6)	(8)	(9)	(10)	(11)
Gonad	2.19E+00	2.50E-01	3.00E-04	1.00E+00	3.00E-04	2.17E-05	1.07E-12	8.31E-10	8.32E-10
Breast	2.75E+00	2.50E-01	3.00E-04	1.00E+00	3.00E-04	2.17E-05	1.34E-12	9.49E-10	9.50E-10
Lung	1.70E+00	2.50E-01	3.00E-04	1.00E+00	3.00E-04	2.17E-05	8.31E-13	8.24E-10	8.25E-10
R Marrow	1.32E+00	2.50E-01	3.00E-04	1.00E+00	3.00E-04	2.17E-05	6.45E-13	8.03E-10	8.04E-10
B Surface	7.25E+00	2.50E-01	3.00E-04	1.00E+00	3.00E-04	2.17E-05	3.54E-12	1.37E-09	**1.37E-09**
Thyroid	1.99E+00	2.50E-01	3.00E-04	1.00E+00	3.00E-04	2.17E-05	9.71E-13	8.48E-10	8.49E-10
Remainder	1.61E+00	2.50E-01	3.00E-04	1.00E+00	3.00E-04	2.17E-05	7.84E-13	7.90E-10	7.90E-10
Effective	2.08E+00	2.50E-01	3.00E-04	1.00E+00	3.00E-04	2.17E-05	1.02E-12	8.48E-10	**8.49E-10**
Skin	3.40E+00	2.50E-01	3.00E-04	1.00E+00	3.00E-04	2.17E-05	1.66E-12	3.71E-09	**3.71E-09**
Lens of Eye	0.00E+00	2.50E-01	3.00E-04	1.00E+00	3.00E-04	2.17E-05	0.00E+00	0.00E+00	**0.00E+00**

* From Table II-9.

** From Table II-5.

Continuation from Previous Page

Inhalation

(9) = (2) x (3) x (4) x (5) x (6) x (7) x (8)

(10) = (Value from Table II-9) * (6)

(11) = (9) + (10)

Submersion

(9) = (2) x (3) x (4) x (5) x (6) x (8)

(10) = (Value from Table II-9) * (6)

(11) = (9) + (10)

with HEPAs	11 km
Dose	(rem)
CEDE	2.50E-04
DDE (eff.)	8.49E-10
TEDE	2.50E-04
CDE (max)	4.47E-03
CDE + DDE	4.47E-03
Lens of Eye	2.50E-04
Skin	3.71E-09

CEDE, DDE, CDE, TEDE Dose Table

CEDE = (11) for effective organ with inhalation

DDE = (11) for effective organ with submersion

TEDE = CEDE + DDE

CDE = (11) for maximum organ with inhalation

Lens of Eye = Skin + TEDE

Attachment III

PLUTONIUM RESPIRABLE FRACTION

ANSI/ANS-5.10-1998 provides a listing of documented, peer-reviewed ARFs and RFs for use in accident analyses. The ARF for glass (ANSI/ANS 1998, p. 15) is from *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities* (DOE 1994, p. 4-52) which uses experiments by Jardine (1982) that reports percentage respirable fines (defined as particles with a diameter of less than 10 microns) produced by impacts of a given energy density. The Jardine work contains data for various glasses and several formulations of SYNROC ceramic produced by both hot pressing (HP) and cold pressing and sintering (CP). Because the plutonium ceramic and SYNROC have very similar bulk compositions, phase compositions, and grain, they can be expected to have similar fragmentation characteristics (Shaw 1999, p. 27). Attachment III lists the data given in Jardine (1982) for the glasses and SYNROC samples that were tested.

The Jardine data were obtained at two energy densities (10 and 140 J/cm^3) for the HP SYNROC samples. The data for the CP samples were taken at an energy density of approximately 140 J/cm^3. Each 1 J/cm^3 increase in energy density corresponds to an increase in the drop height of a solid with the density of the plutonium ceramic (6 g/cm^3 [Shaw 1999]) of approximately 17 meters. An energy density of 140 J/cm^3 would therefore imply a drop from nearly 2.4 kilometers. A typical energy density for a drop inside the surface handling facility of the Monitored Geologic Repository would be on the order of 1 J/cm^3. For reference, the energy density (approximately 0.6 J/cm^3) corresponding to a 10-meter drop is shown in Figure 1.

Potential energy is defined as a body being held at rest that if released can do work (Avallone and Baumeister 1987, p. 3-20). Therefore, the potential energy is equal to the mass of the object multiplied by the acceleration of gravity and the distance that gravity can accelerate the object. The relationship between energy density and height can be found using the following equation:

$$h = E \div mg \qquad \text{(III-1)}$$

where,

h = height of drop (cm)
E = energy density (1 J/cm^3) = 1E+7 (g)(cm^2)/(s^2)(cm^3)
m = mass of material (6 g/cm^3)
g = acceleration of gravity (981 cm/s^2).

Both the Pyrex glass and the SRL-131 waste glass lie on reasonably well defined but distinctly different power-law regression curves (Figure 1). Regression parameters for the fitted curves are given in the legend for Figure 1. The HP SYNROC data define a two-point line with a somewhat shallower slope (in log-log space) than the glasses. Regressing against all the SYNROC data yields a slope very similar to that obtained for Pyrex. In both cases, an extrapolation to an energy density of approximately 1 J/cm^3 using the regression parameters yields a fraction of respirable fines between that for Pyrex and SRL-131. On the basis of these data, it appears reasonable to use the Pyrex data as a conservative upper limit for the respirable fines produced by either the plutonium ceramic or the HLW glass. A drop from approximately 10 meters would then be expected to result in a respirable fraction of less than 0.03% (3.00E-4). This attachment contains a listing of the Jardine (1982) data from ANS-5.10 and the chart of this data.

Table III-1. Summary of All Glass and Ceramic Data from Jardine (1982)

Sample Type	Energy Density (J/cc)	Percent Respirable Fines	Error	Table Number in Jardine (1982)
SRL 131 Glass	141	1.7	0.3	9
SRL 131 Glass	140	1.7	0.3	10
SRL 131 (1) Glass	10	0.14	0.02	6
SRL 131 (2) Glass	10	0.18	0.05	6
SRL 131 Glass	10	0.16	0.05	7
SRL 131 Glass	5	0.087	0.018	7
SRL 131 Glass	2.4	0.031	0.008	7
SRL 131 Glass	1.2	0.016	0.004	7
Hi Silica Glass	10	0.29	0.03	6
Alkoxide Glass	10	0.27	0.05	6
PNL 76-68 glass	10	0.17	0.04	6
Pyrex Glass	141	3.2	0.2	9
Pyrex Glass	140	3.1	0.2	10
Pyrex Glass	10	0.27	0.03	6
Pyrex Glass	10	0.27	0.04	7
Pyrex Glass	10	0.3	0.081	12
Pyrex Glass	10	0.28	0.028	12
Pyrex Glass	10	0.29	0.023	12
Pyrex Glass	10	0.3	0.08	13
Pyrex Glass	10	0.29	0.09	13
Pyrex Glass	5	0.11	0.02	7
Pyrex Glass	2.4	0.052	0.007	7
Pyrex Glass	1.2	0.067	0.01	7
Synroc B (HP)	10	0.15	0.02	6
Synroc B (HP)	141	0.76	0.1	9 & 10
SYNROC D (HP)	10	0.16	0.02	6
SYNROC D (HP)	141	1.2	0.1	9 & 10
Syn 1 (HP)	141	0.91	0.24	8
SYNROC (HP)	140	0.9	0.2	10
SYNROC (HP)	140	1.1	-	10
Synroc C (1) (CP)	10	0.15	0.03	6
Synroc C (2) (CP)	10	0.13	0.02	6
Syn 2 (CP)	141	1.8	0.04	8
Syn 3 (CP)	141	1.8	0.08	8
SYNROC (CP)	140	2	-	10
SYNROC (CP)	140	1.8	0.4	10
SYNROC (CP)	140	1.8	0.8	10

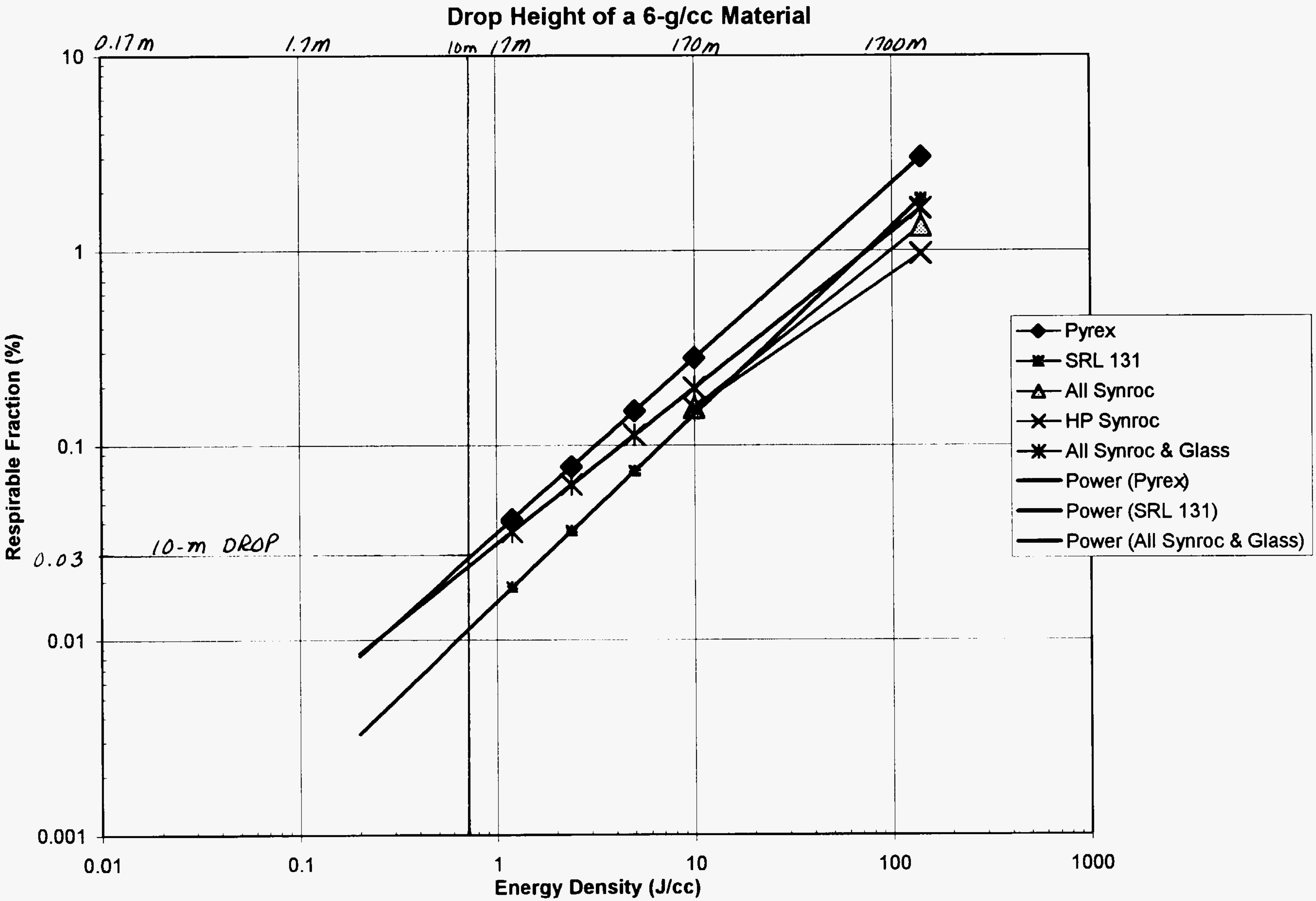

Figure 1. Energy Density vs. Respirable Fraction